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Key issues in the design of science facilities used by grades nine through twelve are presented and analyzed in this extended discussion. Four basic determinants of educational specifications are given as--(1) gross activities and sub-group organization, (2) number of students in the space, (3) services required, and (4) location in relation to school building and site. A procedural planning model is presented which relates goals, methods and facilities. The discussion is based on definition of goals, determination of methods including wet and dry labs, verifying and inquiry experiment, directed and undirected study, and specification of facilities and services. Conclusions relate to methods of determining educational specifications and approaches to planning and research. (MM)

SPACE REQUIREMENTS FOR SCIENCE INSTRUCTION

GRADES 9 — 12

QUALIFYING PAPER

SUBMITTED BY

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OCTOBER 1966

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
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PREFACE

This paper presents and analyzes some key issues in the design of science facilities used by grades nine through twelve. Not all aspects of these facilities for science education are discussed. An architect will notice that this paper concerns, arbitrarily, the immediate school environment—where the student studies science under the science faculty. The paper considers equipment and personnel only as these relatively transient factors influence the design of the enclosing space. Architects often refer to the space discussed in this paper as "internal space," in contradistinction to such an area of spatial concern as community planning.

The school administration customarily gives educational specifications to the architect designing the proposed facility. The architect may optimistically expect these specifications to present clearly the intended educational program, hopefully enabling him to design a functional space.

For a manageable discussion of educational specifications, this paper stresses four determinants of spatial adequacy. These four determinants could serve as the basic organizing concerns in locally prepared educational specifications. To avoid lengthy enumeration, this paper often makes collective reference to the four basic determinants:

1. gross activities and sub-group organization (e.g., reading, viewing opaque projections, individual research projects, team research in pairs);
2. number of students in the space (e.g., twenty-four students per laboratory);

3. services (e.g., gas, sunlight, electricity, water, temperature control, ventilation, air conditioning);
4. location within the school and, to a lesser degree, the site upon which the school is built. (This will be called "situational space.")

This paper will present a procedural model to be used in planning science facilities for grades nine through twelve. The model raises emergent issues peculiar to its creation; such issues are discussed in the first and fifth chapters. Apart from the relationships within the model, each separate planning phase—goals, methods, facilities—is concerned with its own issues, which are mentioned as local alternatives in the second, third, and fourth chapters respectively.

CHAPTER 1

INTRODUCTION: THE MODEL

N. L. Engelhardt and others have found that communities are most satisfied with school building programs when the initial planning phase has been based on the "statement of philosophy" under which the school would operate.[1] After the basic purposes and goals have been recognized, the planning process continues with the next areas of concern.

> The curriculum and the general methods of instruction that will be followed are discussed at length. Class sizes are defined, the teacher and pupil needs are outlined and the space requirements are fully set forth.[2]

This procedural sequence for drafting educational specifications may be represented by the model in Figure One.

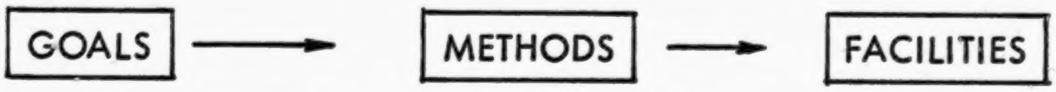

Fig. 1—The model, adopted in this paper, for approaching specifications of facilities.

Scope of educational specifications

Although explicit educational specifications are in demand,[3] leaders in the field of school planning quickly caution educators to allow the professional architect his rightful autonomy. W. E. Martin, a national authority in facility planning, says, "Their [educational specifications] purpose is not to instruct the architect how to design the space but, rather, to acquaint him fully with the needs of the program for which the space is to be used."[1] From his extensive experience in school design, the architect William Caudill feels that "a competent architect would much prefer to have a clear-cut statement . . . of activities which go on within a classroom than a statement to the effect that the classroom should have such and such a shape with such and such dimensions."[2] Educational specifications cast in terms of space requirements, as delimited in the preface, provide the latitude which Martin and Caudill describe.[3] In regard to Figure One, the autonomy of the architect does not begin immediately after methods have been specified. The educator must attempt to aid in the translation into facility specifications in a general manner. For instance, the educator should specify conduits for coaxial cable utilized with computerized teaching machines; the architect will determine the location and size of the conduits. The educator's specification might well go beyond the mere mention of the basic service determinant.[4]

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[1] Engelhardt 1956 p.5.

[2] ibid.

[3] Architectural Record 1956 p.5; Beck 1962 p.12; Caudill 1954 p.21; Cramer 1963 pp.34-37; Martin 1960a p.232; National Council on Schoolhouse Construction (NCSC) 1964 pp.1, 15; Sumption 1957 p.155.

Definition of "space"

The term "space" is not defined by the requirements of accommodating certain activities and numbers of students, having certain services, and possessing specific situational characteristics.[5] Such space requirements only limit the kinds of spaces which an architect could call appropriate. In order to avoid petty concerns and too detailed a description of the four basic determinants, it may aid the educator to understand the architect's concept of space. Provision of space, which involves the design of relatively permanent structures, is the broadest concern of facility planning.[1]

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[1] 1960a p.233.

[2] 1954 p.28.

[3] An excellent example of the limits pertaining to specificity in educational specifications is given in the school planning conference transcript containing a discussion of cafeteria alcoves—Architectural Record 1956 p.236.

[4] For an explanation of "service" and other determinants, see supra p.ii.

[5] This paper's preface contains a more complete presentation of these four basic determinants. The writer considers these factors as the most fundamental and

Space is a physical factor of infinite or finite magnitude in two or three dimensions; being perceived when it is visually or tactually subdivided by material objects, or being perceptible when sounds, heat, cold, pressure, smell, or gravity create discontinuities within the space. But the architect is also concerned deeply with the connotations of space, for he is interested in the use of space. For him, a space adopts the qualities of its contents; so he speaks of a "cheerful space" or a "crowded space"—even though that very same space can be described (in full accordance with its definition) by a line drawing on a blue print. It may help to gain an appreciation of this vague concept by visualizing architectural space as a Gestalt field influencing the perceptions and actions of those within the space. The space's influence is felt often as a disturbance in the equilibrium maintained by our sense

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stimulating. The scope of educational requirements could be expanded with concerns such as specific dimensions of storage rooms. The full domain of educational requirements can be found in the following references: Beck 1962 p.13; Council of Chief State School Officers (CCSSO) 1965 pp.307, 315; Cramer 1963 pp.5, 37; Educational Facilities Laboratories (EFL) 1960a p.12; Sumption 1957 pp.155, 156.

[1] Equipment and teachers fill the "space," and this creates a facility to which students come. If the space is to be adequate, the space must be planned and designed with equipment in mind. Concern for the capabilities (or specific desires) of teachers and the availability of teacher-aides are also factors in the design of spaces. The usefulness of such concerns is limited, because equipment and teachers change much more rapidly than the school building—which has a minimum life expectancy of fifty years. The importance of outfitting the space is recognized, but will not be considered in this paper. (For information on outfitting laboratories, see Grobman 1964 and Richardson 1961.) The use of the word "facility" in this paper is an attempt to avoid the more uncommon word "space;" it is hard to visualize empty space working in a curriculum. By the use of the concept "facility," this paper introduces an intentional vagueness in the domains of equipment and personnel. This loss in clarity should be balanced by the gain in reading ease accompanying the use of the more familiar word "facility."

organs. A discontinuity in the environment is most often the cause of such a disturbance.[1] In a sense, space is synonymous with environment—except that space usually connotes the larger, more permanent structures in the environment.

The architect, in effect, creates space by placing organization within a void. By subdividing space, the architect gives perceptible qualities to the space. These qualities of space may be strong enough to stimulate or restrain a person. Everyone is an architect of sorts, since we all act as a subdivider of space (even by the mere presence of our bodies); but the professional architect is trained to recognize the philosophical and psychological import of his activity. The architect's concerns for the design of space would naturally include more than the predominantly internal space requirements mentioned in this paper. For the specific task of designing science facilities, however, the four basic determinants hopefully will serve as a manageable and fruitful base. There is an hierarchy of spatial design concerns; this paper will concentrate on issues between the high level of planning communities and the low level of equipping science departments with items necessary for utilizing the more general spaces.[2]

As with definitions of many terms, "life" and "baldness" for example, some degree of intentional vagueness fosters a stimulating atmosphere for research.[3]

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[1] For instance, we may not notice the quality of the air we breathe until passing from the city into the country. The quality of the air is an attribute of space, as is anything contained within the space. Relationships between things are also attributes of space. Space can be described by its dimensions (when finite), but it is more often described by what it contains.

[2] The Random Falls Idea does include community planning as a basic concept in school planning. School Building Commission 1960 p.64.

[3] See Arthur Pap (1949 pp.116-117, 290-291) for a discussion of acceptable vagueness.

It also may be the case here, that "vagueness can be reduced, but never completely eliminated."[1] Architectural "space" is truly a concept, not just a word.

Major thesis of the model

The major idea behind the model is that the educator who knows the goals and intended methods of the school system can participate effectively with the architect in shaping the educational space within the classroom and the school site.[2]

Using the model produces educational specifications which are highly flexible in the actual process of designing schools. The architect knows the basic educational needs and goals; this knowledge enables him to modify specifics as the building plan develops. As a consequence, fulfillment of the educator's desires is not so dependent upon other design features.[3] By utilizing the model and the four basic determinants of spatial adequacy, the educator becomes a more effective contributor to the final school plan than does one who only requests specific architectural items.

When educators are aware of the basic goals inherent in the use of various methods, economy and efficiency are possible to achieve for the total school program. The expense of science laboratory facilities may or may not be justified after examining basic goals. The model might stimulate teachers and science educators to look for alternative requirements for many objectives which formerly had only one method of being accomplished. The introduction of newer, more efficient methods of teaching—from growth chambers to computerized teaching machines—will be aided by a thorough analysis of goals, methods, and facilities. The procedure of the model may lead to such analysis.

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[1] Cohen and Nagel 1934 p.225.

[2] This statement may bring to mind the controversy concerning "form reflecting function" found in EFL 1960a p.5. (A list of abbreviations is located on the page following the bibliography.) With the coming of many instructional methods, form had to reflect many diverse functions—a serious problem for the self-contained classroom. In fact, the demands of designing facilities, for yet unknown instructional methods, became so great that reflecting function became an impossibility. Flexibility was the key concept (and it still seems to be), but should not facilities support something more than aimless flexibility? Is true support for certain activities antagonistic to flexibility? This issue will be discussed in Chapter Five.

[3] Suppose some other procedure were used in gathering specifications for a new high school. One such common procedure is to ask the department heads for suggested features. Imagine that this procedure yielded the specific request for

The use of the model presents issues which may lead to new insights in the realm of school design. Underlying assumptions for the model also offer opportunities for research. This paper practices the forward procedure of the model (indicated by arrows in Figure One) but at times attempts the reverse sequence by predicting space-design consequences in methods practiced and in goals accomplished. Research involved with this reverse check on the model generates the same underlying assumptions and issues as did the practice of the model from goals to facilities.

Rationale underlying the model

Generally it is assumed that activities within a school influence the student, but this basic educational assumption rarely is verified without the aid of statistics detecting small, significant differences between methods involving various activities. One reason children seem to learn, in spite of what teachers do, may be that other agencies educate the student outside the school proper. (Specific

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large windows in the biology room. The architect either rejects or accepts this recommendation, because he has no background information with which to design alternatives. If such a specific request runs counter to major design factors (in this case, the factors might be air conditioning and windowless walls), the request would likely be ignored. But the flexible specification for a space, which would facilitate the growing of plants, would still have the possibility of materializing as a growth room using artificial light.

examples of supplementing the school's effect on the student are Philadelphia's proposed Joseph Priestley Science Center[1] and its existent, private Franklin Institute. Even Cox,[2] the director of the Philadelphia Science Center Project, indicates that such a center is a dubious, permanent substitute for adequate facilities in the schools.) There is very little evidence that schools can achieve many of the modern goals of science education, but this is no cause for resignation on the part of professional educators. Educators may elect not to adopt certain goals; but this hopefully is done not out of apathy, but by deliberate decision. A lack of faith in specific instructional methods may have contributed to the drafting of vague and useless educational specifications.[3]

The concerned educator assumes that activities within the school influence the child. The educator may then seek the causes of certain types of behavior to gain control of the influential activity. The obvious cause of most activity seems to be student or teacher intentions; often the student responds to the teacher's wishes, which need not be voiced overtly. There are many factors which give rise to those intentions, such as training and past experience of the teachers, available time, readiness of the students, availability of equipment and tools, proximity to certain ancillary facilities (such as a library), and general supportive nature of the environment. As a homely example, rarely does one find a student drinking water where there is no access to water. (Here the lack of a facility serves as a constraint upon activity.) Conversely, the presence of a water fountain may well suggest to the student a need for a drink. (Here a facility is doing more than allowing an activity to occur; it is suggesting the activity.)[1]

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[1] Cox 1966.

[2] ibid. pp.7, 12.

[3] The reasoning done by some apathetic school personnel might go like this, "Since it really makes no difference how I teach, why go through the trouble of deciding what goals I should have and how to accomplish these goals? It's too much trouble for nothing; therefore, I might as well leave it to the architect to decide what types of activity this school should accommodate. The actual decision makes little difference in what the students learn." Poor educational specifications shift by default the educator's responsibilities to the architect, a situation frequently resulting in educationally inadequate facilities. The educator working with such facilities may take refuge from criticism by advocating that other agencies should accept some responsibility for science education.

So it appeared to many educators[2] that facilities significantly guide the actions of teachers and stimulate the thoughts of many students. This is an assumption which may lead to research at various levels.[3] Until such research is forthcoming,[4] this author will assume that facilities do influence teaching methods. The biologist designates environmental factors which act upon the vital processes of an organism, "limiting factors;" the state of one such factor, when at a critical level, being termed a "limiting condition."[5] The aspects of space considered in this paper are assumed to be methodologically limiting factors, and it is shown how methods seem to require, a priori, certain spaces. Empirical studies could attempt to see if such a priori reasoning actually reflects what is happening in schools.

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[1] This paper will return to this dual aspect of facilities later. Spatial influence on action also can be explained sociologically. Consider that for every action, the actor is subject to a cost (e.g., in effort, time, or respect) and a gain (e.g., in savings of effort or time and in developing stature). The choice of action (or inaction) will be for that which gives the largest net gain or the least net cost.

[2] For support of this statement see the following: CCSSO 1965 p.323; Hurd 1954 p.4; Martin 1960c p.31; Richardson 1961 p.8. Monacel (1963) found that new elementary facilities did not change instructional methods; teachers were a powerful conservative influence in the face of the enthusiasm of children and parents.

[3] Brubaker (1962 p.200) calls for architectural research concerning the tie between facilities and the housed activity. Does a monumental building inspire students to study? Educators adding specifics might ask, "Do students utilize project rooms? To what extent are individual projects done regardless of facilities available?" To aid such research, facilities might be designed to allow randomization of students in large schools which could have a variety of contrasting facilities. Schools-within-schools might provide the ideal administrative system for such experimentation.

[4] Monacel has attempted such research (1963).

[5] Ecological research may provide mathematical models for architectural research.

From the following, it appears that architects would agree with the thesis that space is a limiting factor for instructional methods.

> The educational plant is a means to an end. Its major contribution is to help create an environment which is most advantageous to the success of each child in accomplishing the desired learning outcome planned in the program on instruction.[1]

Educators might object to placing the teaching environment in such a crucial position, as a limiting factor. Possibly this reservation has contributed to the plethora of poorly prepared educational specifications.[2] Regardless of the reason, disregarding requests for complete educational specifications does seem to occur frequently.[3] Once a significant influence of space in science education is acknowledged, it follows that a sophisticated effort should be made to coordinate educational goals and facilities.

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[1] NCSC 1964 p.1; see also Architectural Record (1956 pp.xi, 242) for evidence that facilities did change behavior. Others explicitly assuming space as a limiting factor are Caudill 1954 p.24, Cramer 1963 p.37, EFL 1960a p.5, Sumption 1957 p.155.

[2] Poor examples of practice rarely find their way into print, but two references cite experiencing inadequate educational specifications, Monacel 1963 p.2 and Beck 1962 p.12. The numerous citations given for the support of the thesis in this paper, indicate a need to convince others that educational specifications are worthwhile.

[3] The following references urge that complete educational specifications be made: Architectural Record 1956 p.5, Engelhardt 1956 p.5, Martin 1960a p.232, NCSC 1964 p.15, National Research Council (NRC) 1963 p.viii, National Science Teachers Association (NSTA) 1963a p.2, Sumption 1957 p.156.

CHAPTER II

THE ISSUE OF GOALS

With this chapter, an attempt is made to present the most basic goals representing various science educators. Eventually it will be shown that commitment to certain goals will imply certain methods. In a ninth-through-twelfth-grade track,[1] the basic goals for each year's science course need not be the same. Thus, different grades may have various instructional methods, which in turn require various types of facilities. Even within one course, several goals may be adopted; but later in this paper, it becomes apparent that teaching for all seven goals in any one year of the student's program is impractical and inefficient.[2]

Orientation and types of goals

Scope of concern

Goals discussed in this paper concern not only students preparing for college, but also students terminating their schooling at twelfth or fourteenth grade. Although many educators of the last decade have been preoccupied with scientific manpower needs, the trickle of students entering the professional scientific fields as technicians or scientists makes concentration on their training an inefficient and unjust policy. If science education for the future non-scientist were improved, it could come to pass that future scientists would be effectively taught in the same basic educational program as all students.[1] Within this basic program, various tracks should be allowed so as to permit any student to advance at his own rate.

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[1] As used in educational circles, a "track" means an elective sequence of courses available for a student. Tracks may differ in course offerings to suit individual ability and ambition. See McKibben (1960) for an example of the accepted use of this term.

[2] Such selectivity is not apparent in many group endeavors prescribing model designs—see NSTA 1960b pp.42-43 and 1961.

It therefore appears that goals for science education can be discussed without reference to vocational aspirations, be they farming, technical laboratory work, or housewifery. Since facilities for a vocational program tend to be isolated, this paper will consider the relationship of science spaces to vocational facilities.

Manner of stating goals

There is no dearth of goals for science education; but fortunately, the goals are not all of the same abstractive level. Some of the broadest goals which concern us are not peculiar to science education—but that is no reason to ignore them here.[2] At the opposite extreme, measurement specialists refine goals to narrow specifics so that accomplishment can be measured behavioristically. Such behavioristic goals would fill a book if restated here.[3] Very basic goals can be understood without refinement to behavioristic objectives.

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[1] To the writer, it appears that future scientists may benefit from practical exercises normally associated with vocational training. Two activities might be (1) the planning of irrigation systems utilizing siphons capitalizing on the region's topography and (2) diagnosing the malfunction of a model refrigeration system.

[2] Some science educators have the tendency of ignoring goals which other areas could teach. They say that teaching science is time consuming enough without trying to apply knowledge to such areas as conservation. They advocate that social studies, not science, should teach the application of ecology, which is a topic in the curriculum based on social utility. The development of individual self-reliance could also be shifted to another subject area. Such a stance on many school goals is not defensible (unless coordinated at the local level), because the other areas could also do likewise. This could result in the goal being lost from the curriculum, although there would be agreement that the goal is good.

[3] For samples of behavioristic goals in various degrees of refinement, refer to Dressel 1954a, Hurd 1954, Jeffrey 1966, P.G. Johnson 1962, W.C. Kelley 1957, NSTA 1961, Olstad 1963, Pierce 1959 p.4, Richardson 1961 p.2.

Examples of legitimate general goals are as follows:

1. Education should develop the individual to his fullest capabilities.
2. Every child should be exposed to all types of intellectual endeavor in order to be truly literate.
3. We must pass on our cultural heritage through the school.
4. Our national health and survival depend upon enlisting new scientific manpower from our offspring. We must interest some students in science as a profession.
5. For an individual to survive in a technological world he must be conceptually outfitted to interpret his world in an aesthetically pleasing and in a useful fashion. Superstition is to be supplanted by more adequate attitudes.

The fifty-ninth Yearbook of the National Society for the Study of Education makes a fine beginning for local debate on such general goals for science education.[1]

Suggested alternatives

There are a few goals which apparently reflect current thinking in science education and which have direct consequences in space requirements. If this paper's procedural model is used, local debate may discover more goals with spatial consequences. Each of the following sections is written as an argument for a goal's adoption in order to avoid lengthy formal analysis. These arguments are given only as an explanation of the key terms to be used as reference words throughout this paper; the explanation is in no way an attempt to influence the reader so that he will adopt the goal.

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[1] See also Hurd (1962 p.7), Jacobson (1961), and Nahrstedt (1963 pp.51-56) for more goals which could be effective in starting local discussion.

"Power"

The power of science is dramatically demonstrated in developing countries today. Man's ability to guide nature within the bounds of natural law is told in the story of civilization. Some educators[1] have thought this power inherent in science should be felt by the student in order to gain optimism and poise necessary for fulfilling his own ambitions and desires. This goal has significant implications regarding the empathy students may develop for engineers and applied scientists. This goal's reference word is "power."

"Social impact"

A second goal, referred to as "social impact," is that students should understand how science has influenced intellectual thought throughout history.[2] (Besides the field of intellectual history, anthropology could offer evidence about the impact of technology and science in the early years of society.) The concept of a heliocentric solar system had great—but not immediate[3]—impact on the proud, theologically dominated thought of the Middle Ages which expounded geocentrism.[4] It is a matter of literacy which advocates presenting the historical milieu of science. The limitations of science as one type of intellectual activity should be included as a topic under this "social impact" goal.

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[1] Fletcher Watson (Science Materials Center 1960 p.10) and the American Association for the Advancement of Science (AAAS, 1964 forward) advocate this goal.

[2] For advocates of this goal see Science Materials Center 1960 p.10, Harvard Project Physics 1964 p.4, and NSTA 1961.

[3] See support for this in Singer 1959 pp.247-248.

[4] The classical debates accompanying this issue also lend themselves to excellent discussions of the methodology of science. See Singer (1959 pp.212-223) as an example. Such a use supports the "process" goal (infra p.14).

"Product" or content value

A third goal, here called "product," advocates teaching a certain body of facts or concepts. Although de-emphasized by the newer, national curricula, the goal is probably retained as a major one by most teachers.[1]

Some psychological theory points to the need for concept awareness before the student's perception allows practicing the newer curricular "process" approach.[2]

The current curriculum workers adopting this "product" goal[3] are considerably different from the traditional, product-oriented teacher. The current task is to sift, from an avalanche of information, the basic concepts necessary to perceive the world in a fruitful manner—a concern seldom held by traditional teachers.[4]

"Process"

A fourth goal may well serve the concerns of both manpower and literacy in science education. The advocate of the "process" goal believes that the student should obtain an appreciative picture of scientists and scientific methodology. It is believed that only with such understanding can our citizenry show support and understanding for scientists. Such knowledge should help secondary school students to make valid preparatory vocational choices.[1] Students educated under this goal should perceive the sociological factors in scientific occupations, such as the trend toward team research.

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[1] Obourn (1966) indicates that most science taught is not the newer curricula.

[2] Bruner (1957 and 1960 p.11) and Novak (1964 p.74) present support for this psychological stance. It is interesting to compare these cognitive theories with the first level of the affective domain (defined in Krathwohl 1964).

[3] See Brandwein 1966, NSTA 1961 (for Junior High), Science Manpower Project 1959, and the National Science Foundation (NSF) 1965 p.26 (as part of "enquiry" [infra p.16]). Feitler (1966) represents the vocational training aspects of "product."

[4] Evidence of this endeavor can be found in Montean 1963 pp.35-36 and NSTA 1964 p.16. They do not give the psychological rationale for doing this. Swartz (1966) presents a counter argument to attempts of isolating major concepts. He would concentrate on listing fundamental experiences rather than concepts; he feels the latter lend themselves to meaningless verbalizations.

Understanding science as "process" is often considered a goal adopted during the 1960's. It was the early 1960's which saw the realization of the NSF-sponsored curricula.[2] The "process" point of view was not new; its implementation was dependent upon the creation of cooperative projects in curricular development. John Dewey once remarked:

> For the heart of science lies not in the conclusions reached, but in the method of observation, experimentation, and mathematical reasoning by which conclusions are established. Yet in large measure, it is the conclusions that are taught in schools with a modicum of attention to the methods of controlled observation and testing, upon which conclusions depend.[3]

This did not mean the "five steps of the scientific method" common to texts during the 1940's and 1950's. Only today do we find a sophisticated attack upon analyzing the disciplinary structure[4] and the processes of science.[5]

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[1] NSTA (1963a p.1) supports the above purposes stated for this goal. See other adoptions of the "process" goal in Boeck 1959 p.21, NRC 1963 p.viii, Palmer and Rice 1961a p.7. Feitler (1966) advocates the teaching of specialized vocational "process" in contrast to Beatty (1966) who advocates a non-specialized background prior to junior college.

[2] For a statement of the adoption of this goal by the NSF, see NSF 1965 p.26.

[3] Dewey 1938 pp.480-481.

[4] See Oregon State Department of Education (1965 pp.17-18) for a discussion of the import of this goal. This document is not purely "process" oriented, but contrasts "process" and "product" (termed "content" by them) very well before leading to a synthesis in "enquiry" (infra p.16).

[5] The AAAS curriculum reflects the purely "process" approach of Gagné (1965 p.291).

There is a deep danger for democracies where the populace takes for granted its technology and science, a situation possibly resulting from the sole learning of "product." To Ortega y Gasset a decay of the moral fiber of man is apparent in " . . . this matter of the disproportion between the profit which the average man draws from science and the gratitude which he returns—or rather, does not return—to it . . ."[1]

"Enquiry"

If one merges the last two goals, placing the emphasis on "process," a goal called "enquiry" is formed.[2] The writer of this paper feels that many authors use the term "_i_nquiry" to signify "process" teaching without "product" involvement. "Enquiry" has been a foundation of the Biological Sciences Curriculum Study (BSCS).[3] BSCS tried to ascertain basic and timely concepts in biology and then concentrated on a "process" approach. Chemical Education Material Study (CHEMS) has retained a heavy amount of pure chemistry content (as indicated by their tests) but has stressed a dominant "process" approach in the lesson plan schedule.[4]

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[1] Ortega y Gasset 1932 p.87. See also J.P. Barnard (1956 pp.3-6) for like sentiments.

[2] The originator of this term defines it as such, see Schwab 1963 p.429. Other adherents of the "enquiry" goal include Barnard 1956 p.8 and Oregon State Department of Education 1965 p.18.

[3] Schwab (1963 pp.30-31) states this in a publication bearing BSCS sponsorship.

[4] Chemical Bond Approach (CBA), on the other hand, is highly content oriented. Its laboratory is essentially a verification of basic theory (for a discussion of verification versus discovery laboratory see NRC 1963). Physical Sciences Study Commission (PSSC) physics has arbitrarily selected a basic topic from several possibilities in order to stress "process" to the exclusion of a survey of basic physical principles.

"World view"

A sixth goal, "world view," is formed when "social impact," "process," and, to the greatest extent, "product" are combined. Eventually under this sixth goal, the student should broadly appreciate scientific endeavor and the usefulness of particular scientific findings in normal life. This appreciation implies a world view from a scientist's perspective in certain selected areas. For the "world view" goal, "product" does not center around basic ideas for a science per se but centers around those scientific ideas having the most social utility.[1] The teaching of these socially useful ideas has priority over other activities in the course. The goal entails teaching for the affective domain[2] as well as for the cognitive domain.[3]

Under this goal, cultivated minds are prepared to govern the actions of nations, business, and individuals using the best knowledge available. (Since some "process" is also included, the mind's attitude should permit revision of out-dated theories.) Conservationists hold such a goal for science education.[4] The Green Version of BSCS[5] is an excellent example of a course incorporating "world view" if it is taught by a teacher who feels compelled to complete ecological sections of social import. The Test of Reasoning in Conservation, sponsored by the Conservation Foundation of New York City, evaluates a "world view" in conservation and serves as an excellent illustration of this goal's behavioral objectives.

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[1] NSTA (1961) appears to have adopted this view.

[2] Krathwohl (1964) defines the affective domain.

[3] Bloom (1956) defines the cognitive domain for test construction.

[4] Krutch (1954 pp.186-207) remarks that technical knowledge is not enough for effective conservation; he believes that education should also imbue our citizens with a spirit of conservation.

[5] American Institute of Biological Sciences (AIBS) 1963 (see pages 265-268 for an excellent example). Barnard (1956 pp.6-7) is another example of the existence of this goal.

Ortega y Gasset implies possible educational duties for a society valuing individual worth, rather than making the individual subservient to an intellectual elite.

> The mass-man believes that the civilization into which he was born and which he makes use of, is as spontaneous and self-producing as Nature, and *ipso facto* he is changed into primitive man. For him, civilization is *the forest* . . . The principles on which the civilized world—which has to be maintained—is based, simply do not exist for the average man of to-day. He has no interest in the basic cultural values, no solidarity with them, is not prepared to place himself at their service.[1]

If we are to teach literacy in science, the "world view" goal suggests that we must teach the toil of science as well as the product.

John Goodlad has recently criticized the modern curricula for not being concerned with the social aims of education. He claims this omission is the fault of educators leaving scientist-dominated project groups[2] without aims, a condition resulting in teaching science as an isolated intellectual activity.[3] Perhaps the pendulum has swung too far from the affective goals of earlier eras.[4]

"Individual" responsibility for learning

The last aim of science education to be mentioned involves allowing individuals to progress as far as their talents will permit, largely on their own initiative. This aim is shared with other areas in the curriculum and is consistent with our basically believing in the individual's worth.[5] This goal has large effects on space design; the key word designating the goal is "individual" when reference is made to modification in space design.

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[1] Ortega y Gasset 1932 pp.89-90.

[2] See NSF (1965) for an admission of domination.

[3] This is said in Goodlad 1964 pp.54, 81.

[4] Croxton (1935) is an example.

[5] For evidence of the adoption of this goal see: Brown 1965 p.91; Downey 1965 p.12; NSTA 1961 p.11, 1963a p.3; Palmer 1961b p.10; Trump 1960 p.4.

Function of these goals

Presenting the seven goals serves two purposes. First, it establishes a concise vocabulary to be used in subsequent chapters. Second, it provides the reader with an example of how a choice in methods is established with a priori justification.

The architect will not be the only one to benefit if the school system is judicious in the selection of some, not all, goals. For instance, there may be the question of the teacher who falls behind in her schedule. Should she cover the material or continue slowly, but effectively, stressing "process"? Another teacher, demonstrating the "power" of science using a class-built hydroelectric project on a nearby stream, will inevitably lessen the time available for covering some facts or concepts. The only reasonable determinant of action is the goal adoption for the class.

It would seem that the use of all-inclusive statements of goal[1] is impractical and may not form a justifiable foundation for school design. By the selection of a few goals for each course given in the science sequence, the facilities designed may be more suggestive to activity.[2] Design for specific methods facilitates appropriate activities with a minimum of preparation, and specific methods can only be contemplated when a few goals are selected. To include spaces for all alternatives is also extravagant, as will soon be apparent to the reader. If one assumes that space is a contributing influence determining which methods of instruction are used, a supervisory aspect of space design is evident. When selection of goals is reflected in design, the school system exerts purposeful supervision, achieving some standardization among graduates of certain courses.

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[1] NSTA (1961 and 1960b pp.42-43) give examples of such statements.

[2] supra p.8.

CHAPTER III

THE ISSUE OF METHODS

If one were following this paper's procedural model while drafting educational specifications, the next step would be the discussion of appropriate methods for the school's goals. Under normal circumstances, the local educators can state the requirements for facilities immediately after the instructional method or activity. Such a statement would include the four basic determinants mentioned earlier. For demonstrating the theoretical nature of the procedural model, however, facilities will be stressed in a subsequent chapter of this paper.

Organizing themes

"Process"-"product" issue dominant

Of the seven goals—"power," "social impact," "product," "process," "enquiry," "world view," and "individual"—"product" and "process" prove to be the most conducive to discussion in this chapter on methods. There are a few reasons for the dominant concern in "product" and "process" methods.

First, some goals are composites which contain varying emphasis on "product" and "process." The discussions associated with the latter two goals can serve as comments on the methods for "enquiry" and "world view" goals.

Second, little research has been done specifically on goals other than "process" and "product." For some goals, this situation allows little more than a statement of intuition concerning the best rationale for a specific method. For example, the goal of "power" is probably best accomplished by allowing the student to modify his own environment. Such a modification may be the result of individual, team, or class activity—often as a practical, small-scale project outside the school building. Since few educational-measuring instruments have been designed for evaluating attainment of the "power" goal, we can only guess that mere discussions of applied science serve ineffectively in producing appreciation of "power." Movies and field trips intuitively seem to foster the attitude of amazement and respect for wizardry of scientists, rather than empathy for the applied scientist. The "power" goal stresses the affective domain, which is in great need of new measurement tools.

Third, some goals require little in the way of special space. They blend well with other goals or are implemented in regular academic discussion classes. "Social impact" seems to be of this sort. This goal has direct content ties with the humanities and arts; for example, play-acting could dramatize some of the famous controversies of the past. A physical reflection of the close relationship with English, history, art, and music might be suggested as a situational requirement. It does not seem necessary that the science classroom be near the drama and fine arts center, however, unless "social impact" is taught most of the time and utilizes the auditorium, music room, and art display room. Such a situational requirement may unnecessarily conflict with other goals. Most of the existing curricula merely discuss "social impact," utilizing visual aids to give a flavor of the era under discussion.

Fourth, some goals have severe consequences on facilities, but require another goal to direct the basic method and concerns. Such a modifying goal is "individual" responsibility. This goal's methods can be discussed economically as modifications to a major instructional theme. A non-graded curriculum is an "individual" modification—but notice that the essential method is not indicated until "process" or "product" is specified as the orientation to be modified for "individual" study. The familiar programmed instruction can be an "individualizing" modification if diversity exists in the programs. New computerized programs offer far more flexible instruction than printed ones. Even within team experimentation, concern for the individual can be met by proper assignments which will not intensify shyness or strong-handed leadership. Programmed instruction as a preparation for adult life may have some major drawbacks in transfer value. It is probably best to subordinate the narrow aspects of the "individual" goal by using the goal as a modifier.

It therefore appears that the basic issue of methods centers around the election of "process"- or "product"-centered curriculum. While considering the consequences of adopting each of these goals, the evaluation of the need for laboratory methods will serve as a focal point.

Laboratory instruction

Because laboratories have high expenses in construction and maintenance, evaluating the need for laboratory instruction should be a paramount concern for anyone who drafts educational specifications. Besides narration and textbook reading, there are several alternatives for what is commonly considered a laboratory exercise. In order to evaluate the need for a laboratory, it behooves the educator to contrast variations on the method with which he may be familiar.

The "educational laboratory" can be considered to mean, in its widest sense, any instructional method whereby the student interacts with the subject matter. In non-laboratory work, the student interacts with a secondary authority, such as a teacher or student reporter. Books can present science in non-experimental style, condensed laboratory procedure, or as simulated laboratory work. Several other methods also allow the vicarious experience of laboratory work by giving the data with or without visualization of the actual experiment. The broad meaning of "laboratory" includes actual manipulation of variables as well as simulated exercises.

For science courses, laboratory variations can be described using three groups of adjectives: (1) wet-dry, (2) verifying-inquiring, and (3) directed-undirected.[1] Frequently there are only subtle differences apparent from the wording of the class discussion or lecture involving dry laboratory methods and non-laboratory techniques. For example, if one were to compare Schwab's Invitations to Enquiry[2] to a discussion on water conservation policies, an overt action analysis (such as Flanders' system[3]) might show little difference. It will soon be obvious that not all laboratory methods require the same spaces. The options for laboratory methods classified by the three characteristics mentioned above are as follows:

1. wet verifying directed
2. wet verifying undirected
3. wet inquiry directed
4. wet inquiry undirected
5. dry verifying directed
6. dry verifying undirected
7. dry inquiry directed
8. dry inquiry undirected

One may refer to Appendix B for printed examples of these types of laboratory instruction.

Alternatives

"Product" centered

Is the "product" goal accomplished best by the wet laboratory method of instruction? The assumption behind non-inquiry laboratory exercises is that handling the subject matter aids in mastery of specific concepts, such as the laws of optics.[1] This use of the laboratory also assumes that alternatives will not do as well or better. Such alternatives might be the use of computer-based programmed learning, films, television, demonstration lectures, discussions, and any other simulated laboratory work.

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[1] See Appendix A for definitions of these terms.

[2] Schwab (1963 pp.43-226) contains the Invitations.

[3] Amidon (1963) explains the Flanders' system.

Assumptions of the "product" wet laboratory method.—The basic research, investigating the use of wet laboratory-like situations in aiding comprehension and command of a subject, centers around cognitive psychology. Jerome Bruner, a psychologist, would claim that the structure of the physical sciences could be described by three concepts: (1) the mode of representation—enactive, iconic or symbolic, (2) economy in categorization of phenomena, and (3) power of the deductive aspects (often predictive) of science involving the field of constructs.[2]

Stage four of Piaget's sensory motor period is a perfect description of someone learning the existence of phenomena in a science laboratory through the enactive mode.[3] Since young children do not first learn about the world through symbolism,[4] one might believe that students learn a science by starting with active manipulation of apparatus. At first, only actions can be comprehended (the enactive phase); then images or incomplete definitions are used advantageously in some mental manipulations (the iconic phase); and, finally, an economical method is established for full definition of concepts, consequently enabling complex logical thoughts (the symbolic phase). The laboratory is a teaching aid enabling the natural mastery of "product" by starting from the unsophisticated enactive level.

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[1] Excellent examples of this assumption occur in Dressel 1960 and Hufziger 1954 p.7.

[2] This statement is substantiated by Bruner 1966 pp.44-48. The term "field of constructs" is a common concept in philosophy of science explained in Margenau 1950 pp.81-94.

[3] Bruner's term for enactive mode is explained in Bruner 1966 p.18. Flavell (1963 p.112) is the source of the Stage Four description.

[4] This assumption is based on a Piagetian interpretation found in Flavell 1963 p.121.

Enactive thinking also serves as a check for symbolic thinking which periodically must be tested with observables in nature.[1] Do not think of such a function as scientific method; it is hypothesized as necessary for bringing about accommodation in the Piagetian sense.[2]

Research may eventually investigate the idea that learning must necessarily recapitulate development, but meanwhile many educators believe that working with objects makes it easier to remember and to understand scientific laws.

"Product" wet lab and non-lab alternatives.—Classical comparisons have often been made between wet laboratory methods and non-laboratory methods, the latter presenting a "rhetoric of conclusions."[3] This comparison is in the present section; dry lab alternative techniques will be considered in the section immediately following.

On the whole, preparation of teachers has allowed both directed and undirected laboratories to be conducted with essentially a verification function. By measuring knowledge and application of facts associated with "product," most evaluations of the need for lab work found little difference among laboratory and non-laboratory approaches. For the "product" goal, the evaluatory instruments used were valid. It can be justly said that when wet laboratory were compared to lecture-demonstration and discussion techniques, research[4] has not clearly supported some "product" educators' assumptions.[1] In spite of inadequate evidence supporting wet laboratory work for "product"-centered goals,[2] the NSTA still states:

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[1] See Bruner (1966 p.66) for support of this opinion.

[2] See Flavell (1963 pp.65, 152-155) for support of this statement.

[3] Schwab (1962 p.24) uses this now famous phrase.

[4] When research comments were included among the alternative instructional methods, the main issues were obscured. For this reason, the critique of

> Experience indicates that students often face problems and wrestle with them more successfully in the laboratory than in the classroom. In textbooks it is far too easy to find the answers rather than to search for them. The . . . answers tend to be . . . quickly forgotten.[3]

Nonetheless, empirical research indicates that a large portion of students does not engage in wet laboratory work, especially in the ninth grade.[4]

What activities are needed for teaching "product" as a "rhetoric of conclusions"? Students will engage in viewing films and opaque and transparency projections; listening to records, teachers, and students; reporting library research; writing and organizing reports in teams or individually; and possibly working in the library. The educational specifications will probably be very similar to space requirements for other academic subjects. If the "individual" goal is to be stressed, the groups may become smaller within a large classroom. Scheduling may follow the Trump Plan[5] as with other subjects; in this case, the individual student or seminar groups would be housed in separate rooms.

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methodological research is located in the appendixes. The reader should not refer to the appendix, unless the paper is read slowly. Appendix C pertains to this section.

[1] The wet laboratory does create acquaintance with manipulation of laboratory equipment, but such specific skills are rarely listed as goals in non-vocational courses.

[2] Summary statements to this effect are found in F.G. Watson 1963 pp.1043-1044 and Kruglak 1958 p.32.

[3] NSTA 1961 p.44.

[4] The implications of the NSTA conclusion for instructional methods is not followed for grades seven through nine in forty per cent of the Michigan school districts representing ninety-three per cent of that state's student population (Bowles 1964 p.8). Bowles (ibid.) also found that less time was spent in junior high school laboratory than in senior high or elementary schools.

[5] Trump 1960, 1961. See also Brubaker 1962.

Lecture-discussions are not the only alternative for laboratory work. Programmed learning has received much impetus from the desire to individualize instruction. Often the programs are not simulated laboratories but operate at a symbolic level of presentation.[1] Some levels of science lend themselves to operation in the symbolic mode, especially in advanced chemistry and physics. Success with programmed teaching of "product" is indicated in the literature.[2] Auxiliary use of programmed learning is well established in some schools,[3] but boredom is often a problem even with students of high ability.[4] As Schramm[5] has pointed out, better statements of behavioral goals and research in outcomes of programmed learning are needed to see if application of programmed knowledge is forthcoming in adult life.

What would the wet-verifying laboratory look like if it were adopted as a method? Directed verifying wet laboratory exercises require spatial versatility only with regard to future changes in the specific curriculum. Since activities are planned well ahead of the exercise, storage is kept to a minimum. There is no need to store items whose use is only probable. If the laboratory is individualized so that students are on different experiments, procurement of equipment during class will be a traffic problem. Short films may explain techniques while students are at laboratory stations. Television or film loops could be supplied at lab stations enabling difficult procedures to be demonstrated concurrently with student performance of the exercise. J.D. Novak has done some work with audio-visual tutoring which resembles this use.[1] The laboratory could be separate from the classroom since no proper psychological moment exists for a verifying laboratory. Rigid lab scheduling would not be a hindrance.

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[1] "Symbolic level of presentation" does not refer to the mere use of words, as all types of programs use. The phrase refers to the use of such abstrations as πr^2 for the area of a circle, $[Fe^{+++}]$ eq for the concentration of ferric ion at equilibrium, pressure = force/area, and PV = k. Dressel (1960 pp.40-42) speaks of the wet laboratory as the only way to avoid rote learning associated with highly symbolic thinking. It is felt that purely symbolic learning cannot be applied—possibly due to a lack of Piagetian assimilation and accommodation.

[2] See NSF 1965 p.37.

[3] See Leahy 1962 p.307, Buell 1965 p.288.

[4] See Sayles 1966.

[5] Wilbur Schramm 1962 pp.50-51. See also Reiner 1962.

Undirected verifying wet laboratory would have more flexibility concerning the equipment to be used. Storage room facilities would have to be enlarged, but equipment is still limited in comparison to undirected inquiry. Students would procure equipment from a central stock room as they felt the need. Requisitioning of equipment requires great foresight; this would tend to limit any initiative in setting up equipment. It would be better for the student to go to the stock room as he needed items.

For any directed laboratory, the student time on the experiment can be predicted. Undirected verifying laboratories may require more time for organizing thoughts—but, on the whole, the verifying lab will not require after-class access to the experimental area. Science fair projects are an exception to the access generalization, for they are larger topics often done outside of class.

Inquiry laboratory methods may facilitate "product" acquisition at some later time, but inquiry itself does not insure mastery of certain concepts.[2] It appears that "product" is essentially reliant on verifying laboratories. These laboratories are much more economical and less complicated to plan than are inquiry laboratories.

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[1] For another audio-visual tutorial example, see Surdy 1966.

[2] Swartz (1966) and Stendler (1961 p.832) both advocate that prior experiences should help students in "product"-centered courses at a later age. Some elementary curricula do not have planned exposure; the AAAS program does plan certain exposures, but little effort is made to coordinate non-methodological constructs from one experiment to another. So far the AAAS program is purely "process"-oriented with directed inquiry laboratory.

Dry laboratory alternatives for "product" wet laboratory.—The various kinds of dry labs are accepted as supplementary methods, but can they replace wet labs entirely? The assumption behind dry labs is that the student is able to visualize and recall past experiences which substitute for immediate experience. The student's thinking is in images (iconic phase), not symbolic. Sponsors of dry labs feel that it is this type of thinking, not actually touching and smelling the subject matter, which is necessary for learning. In practice the experiment starts with the data. In some cases, the visualization of the experiment is helped by demonstration methods. Some may feel that a background of experimentation allows more accurate visualization in dry labs. It follows that dry lab success in secondary school may depend on the elementary school's science curriculum.

As with wet labs, verification seems to be the most appropriate function for the "product" dry lab. Inquiry laboratories are a roundabout method for teaching specific facts. The directed verifying dry lab is the most familiar. Film and television are two media commonly utilized for directed dry lab. Programming and Socratic teaching can also be used. Demonstrations, too, are a dry lab technique.

Most films and television shows used in schools today are not recordings of a straight lecture. Some of the AIBS film series are pure lectures, but usually these are not received well by students. For this reason, films and television are considered here as media for dry labs. Films can serve as taking the class to remote places for a field trip or can demonstrate a complicated experiment. Some of these experiences would never be possible by wet laboratory methods; but the question should be raised—can dry laboratories entirely replace "product" wet lab with equal accomplishment of "product" and with a savings for the taxpayer?

Some research has been done on this question, especially in areas where properly prepared teachers were scarce. Although the televised or filmed course may not have been "product" oriented, the evaluatory instruments did measure "product" in most studies. Many of these studies are reported in Appendix D, and they generally indicate that wet laboratory was not necessary for achievement. Monotony of watching someone else do the "interesting" work had serious motivational effects. In contrast, supplementary films are certainly accepted for their effectiveness in stimulating interest.

If the use of television or film for gaining "product" mastery presents motivational problems, certain groups of students considered prone to active behavior, such as ninth graders, may be productively involved in giving demonstrations as an alternative dry lab method. The high degree of success in science instruction by television warrants attention.[1] Whether it is used as a supplement or as the sole method of instruction may depend upon the goals of the course. The assumption that passivity is not offering a major learning experience may be based upon a limited concept of learning experience; namely, the affective and skill domains only.[2] If the "product" of science is our only goal in certain courses, we need only be concerned with the cognitive domain.[3] Palmer and Rice, authorities on physics facilities, assume that " . . . the student finds it very hard to gain more than a superficial understanding of his subject without the practical use of instruments or media."[4]

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[1] See C.F. Kelley (1964 p.157) for support of this statement in a general survey of studies. Namstead (1963 p.144), a "product"-oriented earth science educator, also has pertinent remarks.

[2] Siegel (1960 pp.204, 208) led this writer to this idea; Siegel neglects the affective domain.

[3] Brandwein (1962 p.113) criticizes educational television on non-cognitive grounds.

[4] Palmer 1961a p.4.

If this statement applies to the cognitive domain, "superficial understanding" may be referring to what Gagné has called "word chains"[1] or memorizing without understanding.

Probably the most common practice in "product" teaching, other than lecture, is the use of the demonstration as a directed dry lab. Much of the old research dealing with lecture versus laboratory actually evaluated a dry lab procedure, not lecture. From research, mentioned in Appendix D, it appears that this form of dry lab is highly effective. Of course, a straight lecture with illustrative demonstrations, rather than data providing demonstrations, might have been just as effective. Any type of demonstration method uses services available at the front of the room where a demonstration desk is usually situated. Many experiments are prepared prior to class in a nearby preparation room. Overhead projector use in chemistry is often used to enlarge the view of the reaction. Many physics experiments are also designed for optical enlargement or are carried on with large equipment.

The planetarium is the ultimate in demonstration method and is yet to be critically evaluated. Planetaria owned by either city or school system usually do not have enough staff to conduct a well coordinated instructional program.[2] "Only one planetarium had reported definite procedures for evaluating class visits"[3] in a nearly complete sample of existing planetaria in the United States. Korey assumes that the goals are met by planetaria since school systems are purchasing permanent installations. Unfortunately, it is probably true that these school systems cannot justify the expenditure for these spaces on the basis of instructional goals.

Programmed instruction could be designed as a directed verifying dry lab, having the student guess what would happen when certain things were done or giving practice in inference from data. Socratic teaching can direct responses in a dry lab much in the same manner as programmed instruction. Allowing machines to do the job takes a well designed program but gives each student a chance to participate in the lesson to the fullest extent.

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[1] Gagné 1965.

[2] Korey 1963.

[3] ibid., p.2.

The largest contribution that the Socratic method or programmed learning can make is probably in the undirected lab. The only change is in the ability of the data-giver to respond to a wide variety of experimental techniques. The undirected programmed lesson is best handled by a shared-time computer linked to the schoolroom by coaxial cable. Each student is able to communicate via a teletypewriter and actually dictates what he would have done if in an actual laboratory.[1] The computer may have within its memory a storehouse of natural laws so that the reply tells the student what would have happened if he did a certain manipulative act in the laboratory. Computerized dry lab instruction insures that every student is active, although not at the enactive level. Large groups can be supervised in a teletypewriter room, possibly with a subject matter teacher available for lending flexible help. Oral Socratic group teaching is less demanding of each student, but does not require conduits for coaxial cables and teletypewriters. There is sometimes a problem in finding a Socrates, however. Socratic method is best conducted in small seminar groups; otherwise certain students will be lost. Schwab's Invitations to Enquiry[2] have the advantage of being tried on groups as large as twenty-six but are best tried on small groups.

Another undirected verifying dry lab technique is that of library project reports and review of past experiments. This trains students in library usage and also may impart some factual knowledge about an interesting facet of science. It does not teach the process of how the answers in the books were achieved and often fosters in "product" classes a false appreciation of the immutability of scientific knowledge. Much time can be spent training ninth and tenth grade students in the proper use of the library for projects in science. Often the science class could profitably spend weeks in the library during class hours, being helped by the science teacher. Situational space or special library facilities might reflect the demand on the library if this method is adopted. The removal of books to the science classroom retains the "product" goal motivation but does not allow for the acquisition of library skills. If such skills are not gained in early grades, some science teachers may feel this activity pertinent to eleventh and twelfth graders. It is conceivable that the English department could cooperate with the science department in teaching library skills; this would alleviate one situational space requirement for science.

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[1] Examples of computerized programmed learning are appearing in the literature as time-sharing increases and as adequate laboratory-simulating programs are made. See Coulson 1966, Suppes 1966, and Swets 1965.

[2] Schwab 1963 pp.52-221.

"Process" centered

Assumptions of the "process" wet laboratory method.—One assumption which demands wet laboratory work for "process" teaching is that students will not believe how messy and difficult science is until they try it.[1] It is also assumed that the laboratory in school can turn a student into a scientist for a brief period, enabling him to empathize with scientists.[2] Some "process" educators would concentrate on practicing science in smaller behavioral units than in its totality, which may only be achievable by advanced students. The first assumption summarized is that "process" methods in trying to foster correct attitudes (affective domain) must start with activity.[1] Visualization in iconic mode may be possible with rigorous formal training that scientists have had but not with lower grade training.

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[1] See American Institute of Physics (AIP) 1960 p.73 and Schwab 1960 p.36.

[2] See Shannon (1962 p.257) for a verbalization of this assumption. Other examples of this assumption are found in Leggett 1961 p.82 and Palmer 1961a p.7.

There is a second assumption, perhaps peculiar to this level of instruction. In many ways, the act of "sciencing" resists behavioral description;[2] whereupon, science educators are forced to look at "sciencing" as a composite skill to be learned by acting the part of a scientist.[3] It is interesting to note that Gagné's analysis has derived laboratory behaviors, all of which could be done in dry lab or verbal classroom exercises.[4] It is generally assumed that no philosophical analysis of scientific methodology could present a fair, verbal picture of what science is. Therefore teachers must explain what science is by showing examples.

"Process" wet laboratory instruction.—The wet laboratory is considered essential by all national curricula and many teachers—even those historically oriented.[5] Often coupled with some content, the laboratory is considered the instrument necessary for teaching students how to achieve understanding of natural phenomena. This goal involves both "process" and "product" as true "enquiry," a general goal of national curricula.[1]

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[1] Unzicker (1941 p.42) claims that affective internalizations (defined in Krathwohl 1964 pp.31-35) must have been experienced enactively; no evidence was cited. See also Boeck 1959 p.21, Brandwein 1962 p.113, P.O. Johnson 1928.

[2] For support of this, see Scott (1964 p.117) regarding Polanyi. Compare this stance with the AAAS, Gagné approach which attempts to define the critical tasks of "sciencing."

[3] For support of this, see Bruner 1960 p.14; NSTA 1962 pp.32-33, 1964 p.43; and Shannon 1962 p.257.

[4] See Gagné 1965 p.291. Schwab (1963 pp.45-221) gives examples of dry labs following such a behavioral analysis.

[5] For evidence of this fact, see AIP 1960; Campbell 1962 pp.54-55; CHEMS 1963 pp.2-54; College Entrance Examination Board (CEEB) 1964 p.57; Fitzpatrick 1960 p.147; Fowler 1964 pp.4, 16, 41, 53; Grobman 1964 pp.1, 6; Harvard Project Physics 1965 p.3; Klopfer 1964 p.664; Martin 1960a p.229; NRC 1963 p.3; Olsen 1962 p.29; Palmer 1961a p.3, 1961b p.7; PSSC 1965a p.iv.

The coordination between "process" laboratory work and class discussion does not lend itself to schedules. Often laboratory precedes discussion of the principles under investigation; this timing is especially important in CHEMS[2] and to a lesser extent in CBA.[3] Often a class is involved with a lengthy series of experiments (without intervening class periods).[4] Both laboratory and classroom must be available at any time and for long periods of time, thus prohibiting a scheduled use of a separate laboratory. The class is often involved in brief observations of long-term experiments, exchange of data among groups doing parts of one experiment,[5] discussion during laboratory concerning results or procedure, and visiting among research teams within the classroom which might be doing a different experiment, and multiple simultaneous use of the class space (showing a film and getting data from an experiment at the same time).[6] The "process" approach also wishes to foster an atmosphere of research during class discussions. Educational specifications point to classroom-laboratories where "process" or "enquiry" is a goal.

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[1] For support of this statement, see Brandwein 1958 p.27, Finlay 1962 p.65, Hurd 1964a p.9, Martin 1960a p.244, NRC 1963 p.4, and Tyler 1962 p.24.

[2] See support for this in Campbell 1962 p.55.

[3] For evidence see CBA 1964 p.3. Contrast with Strong 1962 p.46.

[4] For examples see the first week of CHEMS, the six-week BSCS Lab Blocks or PSSC 1965 part II p.1. Finlay (1962 p.70), Hurd (1962 p.9), and the NRC (1963 p.7) remark on this characteristic of process methods.

[5] This occurs in BSCS Lab Blocks especially.

[6] Although these are from the personal experience of the author, the reader can see support for such activities in School Management 1963b and NSF 1965 pp.41-42.

The function of the "product" laboratory was essentially pedagogical verification. In contrast, "process"

> laboratory experiences can no longer serve merely to verify previously stated principles. Ways are sought to encourage pupils to discover ideas for themselves and to learn the sciences by developing, so far as possible, the viewpoints and modes of attack that scientists use confronting problems. It is a conviction on the part of reform leaders that the laboratory is one of the weakest links in the science curriculum.[1]

Inquiry wet labs can be directed, as are most BSCS experiments; but often enthusiasm leads the brighter students into undirected research. The best of the science fair projects are usually inquiry wet undirected laboratory endeavors. Directed inquiry requires predictable, but large amounts of equipment. The undirected-inquiry wet laboratory requires a wide variety of equipment—some of which might not be used every year. Storage facilities must allow for traffic patterns and for improvisation during experiments. Earth science classes[2] and certain areas of biology require outdoor instruction for wet labs. Earth science can scale down some experiments and bring the earth inside, but often lack of outdoor space will require dry labs. Unspoiled (non-landscaped) terrain is best for inquiry field studies.

The evaluation for the efficacy of the laboratory method versus a straight historical or philosophical talk on scientific methodology does not seem to justify the great expense of inquiry laboratory.[3] But testing instruments are crude and may not be revealing the true impact of "enquiry" or "process" curricula.

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[1] NSF 1965 p.26.

[2] Use of the outdoors is supported for earth science in Earth Science Curriculum Project (ESCP) 1964a pp.1-12, 13; Lauda 1963; and MacMahan 1966.

[3] See Appendix E.

The measurement of "process" achievement is difficult, since it involves the affective domain. Even cognitive knowledge of scientific methodology is difficult to evaluate by multiple choice items.

Dry laboratory alternatives for "process" wet laboratory.—The main assumption behind inquiry dry lab is that data manipulation and formation of conclusions from certain experimental designs are the essence of "process" instruction.

Directed-inquiry dry labs are often carried on in discussion groups, certainly of no more than twenty-eight students[1] and preferably around fifteen or fewer as suggested by Trump.[2] Analysis of textbook data is commonly done in discussion-dry lab. Films and television could also do this in larger groups, but the student would not be actively drawn into a discussion and could get lost due to a quickly paced film. Films can give data which can later be analyzed in class.

Undirected-inquiry dry labs include those exercises which have a general topic, but whose procedure must be designed by the student. Only undirected exercise permits practice in experimental design. Schwab's Invitations to Enquiry[3] are an excellent example of such a dry lab. The teacher must be well trained and know responses for unanticipated suggestions as well as those printed in the book. No comparison investigation has been done on the efficacy of this method versus wet laboratory. For some students, the mental gymnastics in logic are not inviting.

As mentioned for a verifying dry lab alternative, computerized programmed learning can be used to simulate laboratory. There is no reason why physical laws could not be eventually read into the memory of a computer so that the computer could tell the student what would happen after the student communicated a manipulative act by means of a teletypewriter.[1] The program need not be a course in methodology, since "overt responding has not been shown to be a requirement for learning from autoinstructional programs."[2] The better the program, the less supervision and help are needed. This type of inquiry dry laboratory might achieve few affective goals. Aspects of scientific occupations, such as team research, would be ignored, unless teletype units were grouped to work as a research unit.

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[1] This recommendation is in NRC 1963 p.15.

[2] 1959 p.9.

[3] See Invitation 25, Schwab 1963 pp.130-135.

As a supplement to inquiry, programmed learning apparatus may be located in the classroom or in special spaces.[3] Research into the potentialities of programmed learning, especially when computerized, is far from dead.[4] If Schwab's Invitations to Enquiry could be computerized, a significant advance might occur in dry lab "enquiry" training.

Some consequences of the "process" goal.—The methods associated with the "process" goal require much responsibility on the student's part; text material is reviewed infrequently in class.[5] The need for study and laboratory skills prompts Weisbruch to recommend a "process"-centered course in junior high school.[6] Science fairs or congresses probably achieve their best accomplishments when inquiry is facilitated by the school plant. Often outdoor field projects are the least expensive in terms of space.

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[1] For examples of computer-centered programmed learning, see Leahy 1962 pp.306-307, Suppes 1966, Swets 1965, and especially Bushnell 1966.

[2] Briggs 1964 p.364.

[3] See a discussion of this in Buell 1965 p.288, Leahy 1962 p.207, NSF 1965 p.37, L. Smith 1962.

[4] Evidence of this use is found in Reiner, 1962, Wilbur Schramm 1962 pp.50-51, and F.G. Watson 1963 pp.1052-1054.

[5] For support other than the author's experience, see Schwab 1960 p.40.

[6] Weisbruch 1963 p.494.

A possible "process" responsibility of the senior high school is to present diversity in the science curriculum especially in physics and biology. Colleges will be specializing in biological facilities required for research and inquiry teaching.[1] In order to acquaint the student with such areas as plant physiology or microbiology, high schools do not need the costly, small-tolerance facilities of college biology departments. For example, plant growth chambers can have five degrees variance in temperature for high school inquiry facilities, whereas this is too great a tolerance for some types of research in colleges.

School site selection should consider outdoor laboratories as part of the classroom.[2] Educational research could concern itself with impediments in the utilization of some facilities such as lakes and marshes. Urban school districts, lacking outdoor space easily accessible to the classroom, might consider the use of summer camps and, during the school session, study indoor aspects of field biology (such as pollution analysis of water samples). Diversity in curricula enables students to appreciate the scope of a discipline.[3] Besides this literacy function, diversity allows a future scientist or technician to choose further education which allows specialization in his tested interest.[1]

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[1] Hull brings up this point in McKinsey 1966 p.163. Physics may also find specialities being forced upon colleges, such as optics and nuclear physics. Wherever complicated and expensive facilities are required for research, specialization will occur among institutions.

[2] For diversity in and specifications for outdoor laboratory work, see Bennett 1965a; Grobman 1964 pp.8, 37; Lauda 1963; NRC 1963 p.33; Richardson 1961 pp.6-7; Sumption 1957; and Woolever 1963.

[3] The lack of diversity in high school biology has possibly contributed to the popularly held identity between medicine and biology.

Ninth grade options

When planning school facilities, the problems related to the ninth grade are quite unique when compared to the tenth-through-twelfth-grade block. If one is to select instructional methods, it is just as important to know what beginning ninth graders have attained as it is to know what they should attain. Attainment involves the cognitive domain, skill domain, and the affective domain— the latter being needed especially for "process," "enquiry," "world view," and "individual" goals. Adequate evaluation techniques and a knowledge of elementary science curricula are necessary to know the beginning ninth graders' status.

One may empirically determine the level of attainment by examination. Testing for "product" or conceptual mastery is fairly well developed and may be an empirical way to find out the cognitive level of "product" attainment at the end of the eighth grade. Empirical determination, however, has no foundation, since test marks are not an indication of the cause of eighth grade attainment. The cause might change without giving any warning through the testing program. Furthermore, an educator would like to predict what such tests will show; consequently, school planning should assess what eighth graders have attained years before any empirical test can be given to them. If based on the intended eighth grade attainment, ninth grade methods will be more stable than those using a pretest as if it were a machine's governor.

It is probably more sensible to guard against abrupt changes in one's empirical findings by delineating the intentions of elementary and middle school science curricula. This procedure is only a "best estimate," since high mobility in our nation compounds kindergarten-through-twelfth-grade articulation problems. Assuming that students cannot adapt quickly to a strange curriculum, many administrators espouse moderate goals. This assumption is yet to be tested.

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[1] Disagreement with this is voiced by the NSTA (1959) in attacking Advanced Placement.

Background of the ninth grader

"Process" centered.—Elementary "process"-centered curricula are of two types: those with goals (which are theoretically possible to evaluate) and those without goals (which defy evaluation). These "process"-centered curricula do not construct their inquiry experiences around a framework of "product" concepts. For "process" curricula, the usual criterion for content is only that the concept allows deep and technically manageable inquiry.

The goal-oriented curriculum[1] will plan inquiry experiences in a program, which hopefully will end with a considerable body of planned content or "product" knowledge. It remains to be seen if grades seven and eight prepare AAAS students for dealing with hypothetical constructs in science.[2] Bluntly speaking, a student who enters BSCS in ninth grade may not know the meaning of a chemical compound, although he can conduct a controlled experiment. A quick review or introduction to chemistry in BSCS cannot instill the understanding that several months in general science could have cultured.

Another "process"-centered curriculum, Elementary Science Study (ESS), offers materials only as guides and allows the student to pursue "sciencing" in a way which is programmed individually by the student.[3] This procedure insures a need for a content summary course in the junior high school,[1] ~~such as Educational Services' Introductory Physical Science Course (IPS)~~.~~[1]~~ Without a summary course, the child will have experienced a wide diversity of phenomena;[2] but he may not be able to communicate through formal scientific language or "signs."[3] With both the AAAS and ESS programs, it is assumed that subsequent learning of conceptual nomenclature will be aided by the background of "process" experiences.

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[1] Such a curriculum is found in Gagné 1966 and AAAS 1964.

[2] For support of this statement, see Atkin 1966 and Gagné 1966 p.49.

[3] At least Hawkins (1965a) has written this philosophy; others at ESS do not have to agree.

"Product" centered.—Atkin's approach is more "product" oriented; the processes of science are learned in a course which is organized around concepts.

> . . . Those who seem to start from a "content" view hold that scientists can make the greatest contribution to curriculum improvement by identifying potent scientific ideas that help children see the essential frame-work of a discipline and how scientists in that discipline have operated.[4]

Several textbook series have strong conceptual or "product" organization, utilizing experiments which verify what the book has said. These experiments rarely are true problem-solving situations,[5] as experiments would be with inquiry laboratory. Newport's study[6] indirectly serves as evidence that at least his panel of future elementary teachers think of elementary science as an introduction to "product."

Vessel[7] indicates much science teaching is still incidental and could not be relied upon for a solid foundation for a ninth grade biology course. In certain geographical areas elementary school teachers often stress biology, leaving students ignorant of basic physical science.[1] Seventh and eighth grades generally do not have uniform content.[2] Fowler[3] mentions the lack of facilities and large classes prohibiting laboratory in the lower grades. There is much concern in junior high science regarding teacher education,[4] curriculum planning, and research.[5] Smedley and Nahrstedt[6] have detected improvement in pre-high-school preparation for such courses as BSCS, but caution must be exercised in deciding what to do with the ninth grade.

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[1] See Hawkins (1964) who urges such a summary. ~~IPS does include "process" but it can be taught secondarily~~. Deletions indicate revision by author, Nov. 1967.

[2] See Hawkins (1965b) who espouses this goal.

[3] For those familiar with Piaget, the term "signs" is much more explicit than "formal scientific language." See Flavell (1963 p.154) for an explanation of "signs."

[4] Atkin 1966 p.1033.

[5] Mills (1960 p.3) defines the problem-solving situation.

[6] Newport 1965.

[7] Vessel 1963.

Ninth grade goals and methods

Articulation.—The goal of the junior high program or ninth grade science course does not have to be "process." Depending upon the previous courses, a non-laboratory course might be justified. It is assumed that ninth grade need not be a terminal course in science; and, in fact, ninth grade seems to serve best as a link to tenth grade biology.[7]

Although previously cited writers often wish to make junior high science, including ninth grade, a sufficient science education in itself,[8] this may not be a logical position to take. If background has been heavily "process" centered, a programmed course in science concepts might be in accord with goals and make better sense in preparing the students for biology.[1] If the elementary school is heavily content oriented, then the student should be gradually introduced to new demands of "process"-centered curricula which he will meet in later courses.[2]

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[1] This problem for one geographical area is seen in Bolen 1953 pp.60-63.

[2] Fischler (1961 p.2) has said this.

[3] Fowler 1964 p.16.

[4] Mayor (1964 p.204) gives evidence.

[5] For support of this statement, see Rutledge 1962 p.270, Commission on Science Education (AAAS) 1965.

[6] Smedley 1963, Nahrstedt 1963 p.vi; see also Fowler (1964 p.17) for a comment on preparation.

[7] See Appendix G.

[8] e.g., Nahrstedt 1963 pp.51-56.

The point at which one begins to prepare for modern secondary curricula depends on when and if earth science is given and whether ninth grade will be used for biology with talented students.

Subject offerings.—Where integrated science is not offered, the alternatives for ninth grade science are usually earth science, general science, and biology. Since space requirements do differ according to courses taught, what to teach in ninth grade is a vexing problem. To a large extent, the offerings in ninth grade determine the twelfth grade opportunities in such areas as Advanced Placement,[3] second courses, or a course in the calculus.[4] The adoption of an earth science course in ninth grade negates such twelfth grade options.

Facilities in the ninth grade may allow for different tracks, thereby enabling a varied selection of twelfth grade courses.[5] With integrated science courses, where lessons or units are not specialized by scientific disciplines, the track can be a function of how fast a student progresses in a non-graded curriculum. With any track, it may be wise to give physical science before biology, since modern biology requires a sophisticated knowledge of chemical concepts, such as molar solutions, molecular weight, covalent bonds, and radioisotope emission spectra.

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[1] See the following for pertinent comments concerning a concept—"product" stress in ninth grade: Brimm 1963 p.107, Karplus 1963 pp.10-11, Rutledge 1962 p.270.

[2] Weisbruch (1963 pp.493-494) argues for "process" preparation in ninth grade for inquiry skill and attitude demands in tenth grade.

[3] For an explanation of this program, see CEEB 1964.

[4] For evidence of second courses, see Cornell 1959 p.13. Here also will one find the recommendation for math courses in lieu of second courses in science.

[5] This does not mean necessarily that the ninth grade facilities should be flexible; the facilities could be specialized but varied. For examples and discussion of tracks, see McKibben 1960.

If biology is placed in the ninth grade, at least two precautions should be considered. These precautions are important because many bright students are given biology as an accelerated science in ninth grade, giving them a free senior year for an optional science. The education of these students may seriously affect manpower pools. The first precaution is that accelerated students should have adequate preparation in the physical sciences before taking biology. Unless this is done, some of our best students are placed at a disadvantage in grasping the true nature of biology. The second precaution regards space requirements for ninth grade biology. It is imperative that our advanced ninth grade biology students have for their use facilities at least of tenth grade calibre. Administrative 5-3-4 or 4-4-4 grade arrangements serve other purposes besides allowing students of high ability to utilize expensive ancillary facilities.[1] Another option is for advanced ninth grade students to have a school-within-a-school located in senior high school facilities. "There is clearly no overwhelming evidence to indicate where Grade 9 belongs."[2]

Earth science may be given as adjunct topics in existing courses or as a special course. Probably it should not be pushed back much earlier than eighth grade, even for students of high ability.[3] Early grade placement is assumed to cause a lack of sophistication needed to give a true picture of the earth sciences.

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[1] For other advantages, see Murphy 1965 p.7.

[2] Conant 1960 p.43.

[3] Bennett (1965b p.473) speaks about this.

Stephenson[1] asks for ninth grade placement of earth science because of reading level. New York and Pennsylvania have pioneered in secondary school earth science courses. Charlier[2] argues that twelfth grade should integrate and summarize the science curriculum using geology, thereby relieving colleges of the burdensome introductory geology course. Manpower goals may not justify this strategic place for earth science. Some school systems have given earth science in seventh grade, but no evaluation of grade placement of this subject has been done.[3] New national curricula will be emerging shortly and studies may ensue.[4]

Integrated curriculum.—The suggestion of using integrated science and/or ungraded high schools[5] may solve the "time problem" regarding the inclusion of earth science; but three basic subject areas, requiring somewhat different spaces, still remain. Should every integrated laboratory be equipped for all three basic subjects—physical science, biology, and earth science? If separate rooms are to be utilized for various phases of the course, what will be the load factors[6] for each type of facility? Martin[7] feels that the decision to give integrated or separate subjects is important in the design of facilities. This may not be so important with biology and chemistry becoming so intimately connected in the newer biology curriculum. The separate subject of biology may eventually need a course of integrated biology-chemistry. Nevertheless, integration of teaching materials is not proceeding at such a rate that one can expect integrated science as a national norm within fifty years.

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[1] Stephenson 1963 p.17.

[2] Charlier 1960 p.297.

[3] See NSTA (1960a p.42) for systems giving seventh grade courses.

[4] Stephenson (1964) serves as an indication of what is to come.

[5] Brown (1961) explains this concept.

[6] "Load factor" means how many student hours are spent in the facility. Here, distribution of hours is pertinent.

[7] Martin 1960a p.232.

CHAPTER IV

THE ISSUE OF FACILITIES

This chapter will attempt to show how various methods indicate certain facilities. Each of the four basic determinants will be commented upon with regard to various methods. The previous chapter has already described most of the activities associated with certain goals. This chapter will supplement that discussion and add the other three basic determinants: size of group, services, and situational space.

Activities and grouping

The statement of activities can become rather detailed,[1] and such detail might serve as a good check for educational specifications. In this paper, more fundamental methods will be considered.

Dry activity

Possibly the most well known attempt at breaking the dogma in school architecture is the Trump Report.[2] In order to bring about more individual self-instruction and smaller group instruction, the large group (100-150+) instruction was prescribed to allow more teacher time for small group classes.[3] Without increasing the teacher-pupil ratio, team teaching allowed student time to be budgeted as follows: forty per cent large group, twenty per cent small group (twelve to fifteen students enabling discussion), and forty per cent individual study.[1] The Trump Plan can easily be adapted to "product" methods, but not "process."[2] With the development of computerized programs, the usefulness of large groups is lessened; it appears that many rooms linked by television or sliding partitions could serve for the remaining large group functions. Trump's suggested three hours per week for individual study[3] is likely to rise with automation and is not realistic if it includes laboratory instruction. Discussions in groups of twelve to fifteen seem appropriate, and this could easily be done by partitioning a conventional classroom at the proper time.[4] In some schools it has been shown that twenty-seven per cent of the student's time in classrooms of conventional size (twelve to thirty in this case) was demonstration-lecture, and only five per cent more lecture exposure occurred with large-group team teaching. It was concluded that the size of thirty students might still be too large to bring about a difference in teaching methods.[5] The group of thirty is not too large for directed-inquiry dry lab by demonstration. Large group instruction was found by Winter[1] to stess individual self-reliance—some students could not accept this responsibility.

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[1] For example, "Lettering of posters and displays" (Richardson 1961 p.3). Hufziger (1954) gives a good listing of detailed activities.

[2] Trump 1959, 1960, 1961.

[3] See Trump 1960 p.6.

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[1] For these percentages, see Trump 1959 pp.8-9. Note that B.F. Brown (1965 p.28) changes these percentages to 20 per cent large group, 40 per cent small group, and 40 per cent individual.

[2] David Beggs (1964) discusses the implementation of the Trump Plan. Large sections were used, and it is obvious from achievement tests and from the use of various media (ibid. p.255) that this school was "product" oriented in science. Trump suggests that new topics be introduced by a lecturer (Trump 1959 p.8), but "process" curricula most often do this in laboratory (CBA 1964 p.3, Crumb 1965 p.135, and NRC 1963). Trump also proposes that examples of problem-solving be given in large groups. Dry inquiry lab approximates this, but smaller groups seem more appropriate (NRC 1963 p.31). But if "product"-verifying laboratory is to be used, no violation of methods is made by the use of large lectures.

[3] Trump 1960 pp.7, 11.

[4] See NRC 1963 p.15 and Trump 1959 p.9.

[5] S. Winter, 1965 pp.93-96.

From the above remarks, it appears that analysis of science facilities should be more attuned to the goals and methods of science, especially as regards the methods concerned with the "process" goal. Let the discussion begin where the last chapter ended, with a number of alternative methods.

Visual aids.—The facilities needed require that film, television, opaque projection, and overhead projection be usable for long (fifty minutes) and short showings. Dry laboratory techniques are increasingly using film loops or short (five or less minutes) films to illustrate talks.[2] Films must be viewed within the lecture or discussion class with a minimum of preparatory effort. To move into a hall or film-viewing room may require so much time that the teacher will not utilize short films. In some cases, only a portion of the class will watch a film—especially if it is specialized and an inquiry lab is taking place for the rest of the class. It may be that only routine observations are being recorded by one-fourth the class, while a film on oceanographic research is shown the others. Notes are often taken while viewing visual aids; this requires subdued light.

After-school hours often allow specialized film showings for from one to five students or repeat showings of complicated films. Other activities, such as make-up work, must go on under the supervision of the same teacher. Usually, there is not more than one group of students watching a film in one afternoon. Free periods could also be utilized for watching films. If the course is filmed, make-up will require more frequent use of space for viewing films by small groups or individuals. The teacher will often preview films during free periods or late after school. Large projection surfaces are not needed for small viewing audiences. Because the preservation of the color image is essential for some films, televising of films in black and white should not be considered unless large group instruction is held for make-up work on video-tape.

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[1] ibid., p.99.

[2] See NSF (1965 pp.41-42) for documentation of this activity.

Demonstrations.—Many demonstrations are now done with adapted overhead projectors.[1] Some physics instruments can be viewed by large audiences, but this equipment is expensive and may not be justified in comparison to wet lab, film, or television techniques. Before planning non-televised demonstrations (television permits close-ups) produced for large groups, the availability of equipment should be assured. Demonstrations can also be given by the instructor to small groups within a laboratory or class, provided the others have something else to do. The desk demonstration at the head of the room is probably the least effective way of showing an entire class of twenty-five students what is happening. On the other hand, the desk does provide a convenient fortress behind which a lecturer can withdraw from the class.[2] Palmer and Rice's suggestion that demonstration classes could exceed forty students[3] is probably based on the use of auxiliary television for close-ups.

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[1] The Tested Overhead Projection Series for chemistry (Alyea 1962) provides close-ups of chemical reactions and some physics demonstrations (water tables-wave action) have been adopted for projection. Petri dish demonstrations in biology have proved useful in introductory sessions. See also Schlessinger 1962 p.69 for proof of this activity.

[2] More seriously, the demonstration desk if situated correctly can hold projection equipment, voluminous notes, and objects to be held up during a talk.

[3] Palmer 1961a p.284.

Display cases and bulletin board areas are space consuming and often are not even appreciated by teachers. They are especially important in non-inquiry curricula. The space saved by not needing large laboratories or storage spaces may be utilized in widened halls, which enable display cases to face on the area that has loitering students. Display cases within a classroom have dubious value. Picture windows (in the hall wall) depicting the act of science within the "enquiry" class may be substituted for display cases which consume space and preparatory time.[1] Windows can also serve as display cases for outdoor phenomena; but, in the absence of good views, elimination of windows can provide added display space. This is not the place to present the physiological and psychological stress literature on totally enclosed rooms—opinions differ.[2]

Individualized activity.—Programs may be used for teaching without laboratory or for simulating laboratory. For this latter use, conduits for coaxial cables must be provided to the sites giving individual instruction. Complete reliance on computers for laboratory training would require more space for teletypewriters than when used only supplementarily; but, because of the computer's ability to adapt, many subjects could utilize the same space—consequently reducing total dimensional space needs for the school.

Individual cubicles, sometimes called Quest Spaces (Q-Space),[3] can be established for dry lab or non-lab work anywhere in the building. The use of many references for one scientific problem warrants close availability of library facilities. Audio-visual aids may also be used within a Q-Space. Access to this space after hours is advantageous.

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[1] Such hall windows would only be effective if the class were going on while other students passed or if equipment were left functioning between classes.

[2] Windowless schools may not affect all inhabitants in the same way. See EFL 1962 pp.65-67. A fourth wall is also useful for storage and permanent equipment stations.

[3] For definitions, see Brubaker 1962 p.200 and B.F. Brown 1963 pp.58-59, 102.

Wet activities and relation to the classroom

Should the laboratory be a separate room or should it be connected to the classroom, forming a classroom-lab? The answer is different for the verifying laboratory and the inquiry laboratory.[1]

Verifying laboratories can be large, separate, and rigidly scheduled because there is no psychologically proper moment for a verifying lab.[2] Martin and Cahoon[3] cite evidence that classroom-laboratories have been thought to be economical. The economy depends upon the course load. Schools larger than 500 students can fully utilize separate laboratory facilities, especially in chemistry, a subject where laboratories are costly.[4] Often combination classroom-laboratories result in poorly outfitted lab sections; this has been true predominantly in biology and general science. The trend of having classroom-laboratories poorly outfitted is not necessary but has historical roots.[5]

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[1] This may have been the reason that Whitney (1963 p.61) found disagreement in the answer to the above question.

[2] See CBA (1964 p.3), which states that only "occasionally . . . the experiment is used prior to discussing the principle in the text." It is probable that careful planning could mesh the occasional "process" lab with a schedule; however, the CHEMS course demands the impossible of such planning. Numerous inquiry labs force the facilities to reflect "process" education. See CHEMS 1963 p.6.

[3] Martin (1960b pp.17, 52) cites New York State and Idaho's recommendations. Cahoon's reference is 1953 p.113. See also Fitzpatrick (1960 p.166) for physical science room economy. Wright (1961 p.60) disagrees.

[4] This is an inference from data in Obourn 1960 p.8.

[5] Obourn (1960 pp.7-9) describes how non-lab subjects developed their facilities into classroom-labs.

Economy may only be warranted in separate class and laboratory facilities if "process" is not a laboratory goal; even the small inclusion of "process" in "world view" invalidates the use of separate facilities. The decision between separate lab space or classroom-lab should be based on pedagogical value, not economy. Large school economizing by the construction of separate laboratory facilities would make most modern curricula ineffectual—that would be gross improvidence for "enquiry"-oriented schools.

The classroom-laboratory has been generally supported by "process" curricula.[1] The classroom-lab allows the teacher to conduct extended investigations,[2] to schedule daily data collection, to provide inquiry atmosphere in class, and to utilize appropriate timing in "process" instruction.[3] Woodburn and Obourn summarize the situation in regard to timing:

> Unless a teacher has equal access to classroom and laboratory facilities, he must be very adroit in programming the "experimentation" stage on the days his students are scheduled to use the laboratory. If it were not for scheduling difficulties, students should go into laboratory only as, when, and if individual laboratory work holds promise of being the most efficient means to accomplish the day's work. How closely the laboratory exercise is meshed with the textbook and other learning activities is an important criterion of the probable success of the exercise.[4]

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[1] As evidence, see: Fischler 1961 p.115; Fitzpatrick 1960 p.166; Grobman 1964 pp.9-10; W.E. Martin 1960b p.6, 1962 p.21; Nahrstedt 1963 pp.55-56; NCSC 1964 p.52; Olsen 1962 p.29; Schwab 1960 p.36; Woodburn 1965 p.369.

[2] For evidence, see CHEMS 1963 pp.6-54, Campbell 1962 p.55, Finlay 1962 p.70, PSSC 1965b pp.1-2. BSCS Lab Blocks last for six weeks and are capable of filling five double periods per week.

[3] See Leggett 1961 p.80, PSSC 1965b Part II lab notes p.1, Stollberg 1953, and Turner 1964 p.81.

[4] Woodburn 1965 p.369.

The awareness of the school designer regarding classroom-lab requirements has not always been correlated with the states spending the most on education. Alabama, Connecticut, and Florida were found by W.E. Martin[1] to be the only states recommending classroom-labs for pedagogical reasons.

The safety within a classroom-laboratory has legal implications regarding eye protection of those in dry and wet activities during simultaneous multiple use.

The grouping within a wet lab depends upon whether it is verifying or inquiry oriented. For the efficient use of time, various phases of complicated "enquiry" experiments are done simultaneously by teams.[2] The traditional size of the laboratory-classroom (twenty-four students) allows convenient breakdown into teams, even if two classes are combined for laboratory.[3] Laboratories with provision for more than forty-eight would not allow all students to know what was going on throughout the lab. (It is not generally recommended that the number exceed twenty-four.)[4] With BSCS, these teams are four to six students each,[5] in physics the convention is two,[6] and generally groups of two or three can augment individual laboratory without violating college expectations of a "lab course."[7] Research on the optimum size of sub-groups is non-existent; but team research as "process" is taught by team research itself, not by mentioning that team research is a common occurrence today. Extremely large laboratories (100 or so), usually associated with "product"-centered curricula, need laboratory assistants; large laboratories usually stress directed individual laboratory. Safety, ventilation, and air conditioning are factors to consider with large-room instruction versus small-cell work spaces.[1]

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[1] 1960b pp.6, 9, 13, 17 respectively.

[2] Support is found in Abraham 1961 p.9, Andrews 1964 p.21, and Turner 1964 p.83.

[3] One class should be around twenty-four, but two could combine. See Grobman 1964 pp.9, 11, 57; Leggett 1961 p.81; Wright 1961.

[4] Whitney (1963a p.31) states twenty-four as a maximum by consensus. Grobman (1964 pp.11, 57) showed class size an important aspect in BSCS achievement beyond thirty; this could be correlated with a third factor. See also D.E. Miller 1962 and NRC 1963 p.15.

[5] Dawson 1964 p.601.

[6] Palmer 1961b p.7, CEEB 1964 p.142.

[7] NRC 1963 p.31.

Stress on individual projects should have spaces designed for retaining experimental set-ups and for fostering study.[2] Access to advanced-science project rooms should permit utilization during vacations, especially for the care of animals or plants.[3] Individual work need not be done solely by the "project" method; it can be stressed by designing undirected wet laboratory activities[4] or auto-tutorial booths with directed activities.[5] Mahan[6] does not believe the individual problem-solving situation need involve modification of laboratory facilities. The role of the teacher is crucial in an "individual" goal-oriented laboratory stressing problem-solving.

In summary, the classroom-laboratory carries on all "process"-centered activities. Technique films and television demonstration of procedures should be anticipated. Two groups may be in wet and dry situations simultaneously.[1] Verifying labs are usually more stereotyped in activity, just working with the normal lab apparatus. The inquiry lab includes all activities that a researcher does, such as reading, talking, and arguing, blackboard posting of data for others, calculating, and improvising with equipment from the stock room. The requirements for specific courses will be discussed under services, since activities when specific naturally lead to services.

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[1] Architects should consult the following for technical warnings: Lewis 1962 pp.82, 85 and Werner Schramm 1960 p.135.

[2] School Management 1963a pp.59-60, 67 states this.

[3] Some modifications go beyond supplemental provision for individual work; see B.F. Brown 1965; EFL 1960a, 1960c; Trump 1959 p.8.

[4] CBA (1964 p.4) advocates this.

[5] For examples, see Surdy 1966 and Trump 1961 pp.131-134.

[6] 1963 pp.26-55, 57.

The creation of integrated courses is a manifestation of the increasing common core of knowledge needed in high school sciences. Besides the extra enrollment in later grades and in service modifications, new activities can result from integration. The most flexible situation, lending itself to non-graded schools,[2] is to organize multipurpose facilities or place the school on a fifteen-minute modular schedule, allowing complete individual freedom in moving among specialized spaces. A team of teachers could supervise work in specialized laboratories. Such an arrangement might also have individual study spaces outfitted with basic services, instilling individual responsibility for learning.[3]

Ancillary space

Wet laboratory requires much more ancillary space than dry laboratory. For dry lab, space for storage of audio-visual aids (including charts) and books is all that is needed if no demonstrations occur. Minimal preparation and storage space is needed for demonstrations. The number and type of demonstration will determine the dimensions of the space needed. With wet laboratory, the school becomes a gigantic research organization if it is "process" oriented. Verifying labs need only a predictable part of inquiry laboratory ancillary space. By discussing the space requirements for inquiry ancillary facilities, facilities for verifying lab will also be covered.

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[1] Movable partitions allow for this in the Santa Ana, California, High School (School Management 1963b). See also CCSSO (1965 p.324), Fitzpatrick (1960 pp.147-149), and NSF (1965 pp.41-42) for evidence of visual aid use.

[2] For a discussion of non-graded high schools, see B.F. Brown 1965 and Bruner 1965.

[3] For this individual modification, see EFL 1960c p.14; School Management 1963a pp.59-60, 67, 1963b.

Storage and preparation rooms have long been neglected in school planning.[1] There is advantage in having these rooms adjacent to the laboratory with undirected laboratory, and to a lesser degree with directed lab. The size of a room to house materials needed for an "enquiry" class would be nearly equal to the laboratory itself. The situation becomes manageable when directed exercises are staggered or when undirected activities vary the equipment demands. Such activity enables the use of a central storage room which is more economical than classroom storage.[2] Chemistry and biology could share storage space for chemicals and certain glassware items. Washing of glassware might occur in a dishwashing room housing a machine. Wheeled carts could carry glassware to a central location.

Physics equipment should be kept separate from chemistry equipment because of corrosion. Biological optical equipment could be stored with physics equipment in another stock room. Frequently used items should be stored in the classroom unless expense demands sharing. Mobile carts for microscopes solve one large problem in biology, but doors between rooms should allow a teacher to move microscopes quickly, rather than waiting until classes start before moving them.

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[1] For confirmation of the inadequacy of storage facilities, see Felton 1959, Martin 1960b, Redfield 1960 p.62, and Wright 1961.

[2] Central storage enables more constant use of equipment and buying of chemicals in quantity. Small inventories are kept, since hoarding of private equipment stores is held at a minimum. The tendency toward hoarding is verified in McKinsey 1966 p.178.

Perimeter storage in the classroom does avoid traffic problems at the dispensing door of a stock room, but carts could be used to dispense needed equipment for directed inquiry.[1] If peripheral storage is used, multipurpose rooms require more storage space than single subject rooms, unless the Hamilton Roto-Lab unit is installed between the lab and adjacent stock room.[2] The Roto-Lab will also allow safe storage of set-ups remaining from one period to another. Dimensions of rooms might be enlarged to allow cabinets around the periphery. Space for a slanting ladder to reach high cabinets could also be allowed. Shallow storage is practical for chemicals and glassware but not for geological specimens and maps which customarily take three-foot-deep cabinets. The recommended dimensional size of storage rooms per class of twenty-five students, not including preparation area, varies from 125 to 250 square feet.[3] Research is needed to determine the effect of centralization and the adequacy of these conventional figures.

Project storage is a separate problem from dismantled equipment storage. Usually, set-ups must stay where work is performed. The Hamilton Roto-Lab can aid, or separate project stalls can be constructed. Class work can often be left in conventional rooms which have one teacher, rather than a shift of teachers and subjects.

The next most serious problem in ancillary facilities is that of the vivarium. Lack of available live specimens for biology can stifle any "enquiry" program. Several types of specimens are possible; specialization in the use of one type does not restrict the discussion of basic topics. Vertebrate animals, aquatic invertebrates, plants, and microorganisms—all have the same basic life characteristics. Nevertheless, if diversity is assumed as a responsibility of the high school, facilities should permit growth of all types to some degree. Since there are vocational opportunities connected with microbiology and plant growth, technical training programs could be run in conjunction with maintenance of a constant supply of living materials. Small vertebrate animal-raising shows limited opportunity as a skill in the general labor market, and invertebrate aquaria-keeping has almost no market. Experiments on vertebrate animals are technically complicated in mere facets of maintenance. Federal regulation might well rule out vertebrate experimentation in non-vocational high school within the next two decades. Aquatic invertebrates require knowledge of technical culture which should be easily mastered if the proper facilities exist. Many experiments lend themselves to invertebrate use. Of the most useful specimens, microorganisms and plants seem to predominate. The specific requirements for ancillary biology facilities will be discussed under services (specific activity and services—vivariums). It must be remembered that experiments will go on within these facilities, since environmental control is often a variable. Vivarium facilities, therefore, have a supply and experimental function. This can be reflected in design. The use of movable commercial plant growth chambers for experiments usually results in a demonstration dry lab, since these growth chambers are small and expensive.

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[1] See a thorough discussion in Grobman 1964 pp.15, 23-25.

[2] See this unique invention described in Palmer 1961a p.216.

[3] For support of this statement, see Hufziger 1954 p.26, Palmer 1961b p.20, Savage 1964 p.49, and R.C. Whitney 1963a p.31.

The efficacy of a separate workshop for physics needs to be compared to the use of normal shop facilities in the school.[1] Some physics teachers feel that the designing of a measuring instrument teaches much about physical principles and therefore have shop work as an integral part of physics.[1] Often, improvised equipment is necessary for all subjects. Highly structured workshop facilities may go unused when a turnover of teachers occurs. In actual research, most physicists have others actually tooling equipment. It would appear that a natural reflection of the need for scientific apparatus makers could be established in the vocational division of a school. College preparatory and junior engineering aspirants can offer much to each other in school, as is done in adult society. The conversion of "craft"-oriented shop courses to "service"-oriented courses may solve the ancillary facility problem of science and create greater motivation for vocational students. This close coordination will be discussed under situational space.

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[1] Advocating separate facilities: R.C. Whitney 1963a p.31 (Regional differences—R.C. Whitney 1963b pp.57-60);
Advocating use of nearby shops: Palmer 1961b and D.E. Miller 1962.

Attention must also be paid to the service function of extracurricular activities. Darkroom facilities foster acquisition of vocational and avocational knowledge. The darkroom is also invaluable with radiation experiments utilizing radioautograms as detection devices.[2] Radio and meteorology clubs can also use a room and roof facilities with connecting conduits. After-hour access can be advantageous.

Any auxiliary room should have entrance to the corridor or outside to avoid class disturbances when aides or other classes enter and leave the room.

Teacher activities

This section deals with the activities of the teacher when not scheduled with a formal body of students. It appears that in many schools most expectations of teacher behavior were that teachers rested in the faculty lounge, possibly correcting papers and doing register work or that teachers prepared lab apparatus in a preparation room adjacent to the classroom. Activities aided by the teacher's having a free period in his own classroom have been forgotten in the attempt to utilize class spaces ninety per cent of the time.[1] The mention of such activities might allow a compromise brought about by skillful architectural design.

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[1] PSSC presumably feels this way. No printed reference could be found.

[2] D.E. Miller (1962) and Wright (1961 p.85) both cite darkroom facilities as being needed by all sciences.

Some educators[2] have thought that placing a teacher in his own classroom during free periods enhances his teaching ability through creating an individual atmosphere for his classes. Posting bulletin board displays, reorganizing equipment, setting up complicated experiments, and cleaning up the aftermath of a hectic experiment used to occur during free periods. One who expects this to occur after school does not realize the impact of "process" instruction. Science teachers are busiest after school with lab squads, remedial teaching, team teaching meetings, and extracurricular activities. Most experiments must be done once before risking class time, and often technical details are not ironed out until three or four trials have taken place. The teacher supervises the lab squad's work while doing other chores—the teacher in effect behaves like a project leader in a high-powered research center. If there are not enough laboratories to accommodate all science teachers after school, some teachers will probably neglect the laboratory phase of their course.

The teacher should also have a desk, file, and confidential place in which to counsel students. Some curricula will necessitate the teacher's changing from business attire to field clothes. Previewing films, producing visual aids, and ordering equipment also occur between periods. The teacher will probably function better if he is given his own office or shares one with another teacher who has different free periods. (Paraprofessional help, used in large labs and ancillary facilities, will also need desk space.) An office allows a person to place himself in a suggestive space for original thinking and orderly management of lab squad and classes. A teacher may become quickly disorganized and be forced to do mediocre teaching if he must carry books, notes, papers, and letters from class to class and then to an all-purpose faculty lounge.

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[1] AIP (1960 pp.93-94) advocates arguments against the 90 per cent utilization trend.

[2] One such educator is Savage (1964 p.4).

A final note on teacher activity mentions his access to facilities. Inquiry wet labs require that teachers and laboratory aides be able to enter all science facilities at any hour or day of the week. To prevent even a part-time laboratory aide from entering a lab at an odd hour may stifle experimentation. Facilities may have to reflect isolation of science rooms for security purposes, especially when students are also allowed after-hour entrance.

Group size and load

Load

The load factor will not be stressed in this paper; only a few comments will be made about the relevance of space. Load is the total number of hours one student spends in a facility multiplied by the number of students taking the course. Several educational factors tend to increase load. The design of a campus-style high school will suggest to teachers use of longer periods.[1] The use of free room periods must be considered as an addition of pupils. The creation of an integrated science course will raise enrollments in eleventh and twelfth grades.[2] With separate laboratory facilities, the number of laboratories per week must figure into the calculation of load. Frankel[1] recommends five double periods per week for Advanced Placement Physics. It appears that the trend is for all "enquiry" sciences to need 110 minutes per day, while introductory "product"-centered courses usually have one or two double period labs per week. For directed laboratory, exercises can be locally determined and the time-load factor calculated. Although advanced courses can often have five double periods per week, lengthening of the school day will probably occur before all "enquiry" courses are allotted double periods for a full week.

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[1] This was the case at Charlotte, N.C.; see Architectural Record 1956 p.228.

[2] See Martin (1960a p.231) for this finding.

Group

The size of the group has already been discussed to a large extent, since activities are so dependent on group size. Brown[2] feels little need for the medium-sized class[3] in the ungraded school. The departure from this normal class size is not found in Martin's survey of state recommendations.[4] Frankel recommended seminar-sized classes for Advanced Placement Physics.[5] Palmer[6] cites that verifying physics classes were usually 30 to 40 but were also taking place in divisible lecture halls of over 100 students. Most recommendations for inquiry class size are between 20 and 40, predominantly 24—a small conventional size.[7]

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[1] 1963 p.59.

[2] 1965 p.47.

[3] EFL (1960a p.13) offers a summary of group nomenclature. Four to five students is small, ten to fifteen students is a seminar, twenty-five to thirty-five students is traditional or normal, larger than fifty is a large group.

[4] Martin 1960b.

[5] Frankel 1963 p.59.

[6] 1961b p.11, 1960a p.284. Testing "product" learning under Trump Report recommendations, Winter (1965 pp.33, 50-55) found support for large group instruction of 78-153.

[7] supra p.55. See also NRC 1963 p.15; Palmer 1961a p.279, 1961b p.20; Wright 1961.

A recent trend to increase laboratory size from twenty-four to fifty or more has been cited.[1] This can be done for verifying lab easily, as long as supervision is maintained. It does not seem appropriate for inquiry laboratory, as was pointed out earlier. If this paper's reasoning is correct, there is danger in the architectural trend proceeding in a direction opposite to curricular trends.

Services

General dry activity demands

Services required for film and television are dull light, adequate ventilation, and conduits for each room to allow for coaxial cables or antenna wiring.[2] For television production, the electrical requirements should be planned expressly by the manufacturer of the equipment.

Individual hook-ups for television may be used, especially where a variety of activities can be anticipated. Such small-set reception can also be utilized in laboratories which may require hook-ups near lab stations.

Computerized programming also needs coaxial cable. Conduits should be planned to current instructional areas as well as large assembly rooms.

For optical demonstrations and with opaque projectors, complete darkness is needed. Furthermore, sunlight is not necessary in science, and most of the time it just gets in the way. Air conditioning does not necessitate windowless walls, but lack of windows usually necessitates air conditioning. The advantages of air conditioning have not been statistically figured with any sophistication.[3] Air conditioning has reduced costs in some cases[1] and does allow the school to be used year round. The use of windowless classrooms has drawbacks[2] which are not yet fully understood.

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[1] Cited in NCSC 1964 p.58.

[2] These requirements are from Hurd 1954.

[3] This is true despite the large Florida project by F.F. Christian 1963.

General wet activity demands

In laboratories as well as classrooms it must be possible to show short, colored movies. Sunlight should be excluded while showing films, and subdued light should be available for note-taking.

Because of odors and fumes, all biological, chemical, and general science storerooms and most ancillary facilities should be well ventilated. Corrosion dangers are reduced by ventilation, and a healthy atmosphere for lab assistants is thereby provided.

Air conditioning may create problems for operation of fume hoods if no supplemental air is provided. Special hoods are on the market for this purpose, or the architect can provide supplemental air at 50 to 125 cubic feet per minute per hood.[3]

Treatment of radioactive wastes should be of no concern with "general license" facilities, unless septic tanks are used. In this case, avoid the use of any long-lived, non-gaseous isotopes. The chance of septic tank workers being exposed after several years of accumulating isotopes warrants this precaution. Disposal of C_{14} can be done by conversion to CO_2 under a hood, rather than by flushing into the septic tank. Precautions cited in the literature come mainly from persons not familiar with the full story behind radioisotope work in high schools.[4]

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[1] For support of this statement, see EFL 1962 pp.65-66.

[2] Cautions are in EFL 1962 pp.65-66 and NCSC 1964 p.122.

[3] Lewis (1962 pp.41, 90, 330) gives specifications.

[4] Schlessinger (1962 pp.72-73) is an example.

Electrical power for most work is now handled well through portable units. Two 30-amperage, 110-120-volt AC circuits should be ample for most laboratories; outlets should be three pronged but usable by non-grounded appliances also. Service should be provided for special individual hook-up of 220-volt appliances. This is equally important for preparation rooms as well as for classroom-laboratories.

For laboratories above the first floor, adequate noise and vibration preventers can be installed. This is especially necessary if floor centrifuges, dishwashers, or table movement are planned.

Since the various subjects will have their own peculiar activities and service needs, it seems advantageous to mention these special needs in one place. Below, the various subjects and vivariums will have comments made concerning activities as well as services.

Specific activity and services

Earth science.—Earth science classes could easily utilize field excursions for "enquiry" goals; access to fields should be direct from class in order to avoid disturbing other classes by hall noise. Small groups of interested students may use the roof of tall schools for odd-hour observing of horizon phenomena. The roof may also be used for meteorological equipment. The indoor laboratory for earth science should allow a three-foot-deep cabinet around the perimeter for storage of maps and specimens without crowding students. Classroom storage allows spontaneous reference to maps and specimens during class discussion and fosters student initiative during laboratory. Some equipment is bulky, and dust-free storage is a requirement.[1] Flat, movable tables with perimeter or island services of 115-volt electricity and gas would be used.[1] Ice is often needed. Water is used in large projects with sand or dirt troughs. The floor space should therefore withstand water and sand spills— a factor which has significance for situational space. A large (eight-by-ten-foot) sand floor space with drain could be incorporated into a ground-floor room or a central patio, protected for all-weather use. Large, shallow sinks (two by three feet, nine inches deep) with adjacent counters for experiments and cleaning would occupy one or more walls. Polishing, acid rinsing, and dirty chores are to be expected in the earth science classroom-laboratory. Polishing and cutting machines may find their way into the future classroom-laboratory, thereby creating the need for a protected space for safety and prevention of oil spray damage.

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[1] ESCP (1964b) gives evidence of this requirement.

Introductory physical science.—Except for specialized features of earth science (storage, sand pit, and machinery), Fitzpatrick's[2] educational requirements for general physical science are much the same as for earth science. Simple, movable, flat-topped tables are usually mentioned as facilitating experiments.[3] Demonstration desk and deep sinks for individual chemical experimentation were listed as a requirement by Smedley.[4] It may be true that physical science lends itself to less group work and more individual set-ups needing special counter storage space not available on moving tables.[5]

Large water tables could be used in buoyancy experiments coupled with "engineering" projects.

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[1] ibid., pp.6-1 and 12.

[2] 1960.

[3] Marean 1966 p.20.

[4] 1963.

[5] See mention of this in Batten 1961.

Biology.—Services for biology should be available for the entire length of the wall for more permanent equipment and set-ups.[1] Other services could drop from the ceiling or come from under floor plates. The placement of services on desks creates an inflexible situation which hinders team work on many experiments. Desks can be moved to outlets for utilities.[2] Desks are usually for two pupils.

Classroom-laboratory services needed are hot-cold tap water; distilled or deionized water (only for large schools or advanced labs); fuel gas; pressurized air, possibly vacuum (faucet adapters can be substituted); high amperage 115-volt electricity; and, especially, large sinks with debris-catching traps. Preparation rooms and well supervised sinks may also have garbage disposal units which deserve plumbing which can take the debris.[3] A fume hood for each classroom-laboratory of twenty-four students is suggested by some BSCS personnel.[4] Ventilation should be provided at counter levels if it is contemplated that much sorting of ecological specimens in formaldehyde will take place. Since this work is done under microscopes, fumes are especially irritating at that close a range. Air scoops could accomplish removal of irritating fumes and substitute for a fume hood.[5]

Some special services for preparation rooms can be provided. Deionized water (the more economical unless hard water is present) or distilled water is needed in large quantities.[6] Room units can be mounted on the wall for processing of tap water, but piped distilled water is economical for very large demands. If plant nutrition experiments are contemplated, glass distillation is commonly used; deionization may work, but piped distilled water will not, owing to recontamination of the water in trace amounts. (This is an objection only with trace element experiments.) Steam in classrooms appears to be dangerous, but in advanced classes and preparation rooms it can be a time saver (its pressure should be 1.5 atmospheres[1]). For sterilization uses of steam, see the section on vivariums.

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[1] Compressed air for aquaria is an example.

[2] Recommended by Wright 1961 and Hufziger 1954 p.124.

[3] For support on these services, see Dawson 1964. Sewage disposal is recommended on page 603 (ibid.).

[4] Abraham (1961 pp.8, 10) remarks about sinks not being sufficient in most BSCS classrooms and suggests a fume hood.

[5] See Lewis (1962 pp.41, 92) for specifications.

[6] Werner Schramm (1960 p.45) contrasts economy of the two.

Ultrasonic disintegrators[2] used in tissue analysis and microbiology often have contaminating high-frequency audible noise. Unless the room is "soundproofed," the noise is next to impossible to eliminate through isolating the unit. The sound is not dangerous but may annoy occupants of the room or adjacent rooms. Some disintegrators do not produce the contaminating sounds, but they may not be as effective as the "noisy" ones. The disintegrator is usually used during an experiment, not in preparation for them. Educational specifications can be adapted to equipment noises after the equipment has been selected.

Vivariums.—A large factor in any "process"-oriented biology course is the ability to maintain a ready stock of experimental organisms and to perform experiments with living organisms. The space used for maintaining these organisms is called the vivarium. Because vivariums often have environmental controls, experimentation is also a function of these ancillary facilities.

Small vertebrate animals—guinea pigs, rats, mice, hamsters, mature frogs, tadpoles, fish, and chickens—have been used in high schools with excellent results. Although some facilities have been planned for larger animals, such animals are rarely used. If more than one teacher uses the classroom-laboratory, disturbance to other classes can be avoided by placing animals in another room. The author has seen a situation where an unappreciative chemistry teacher was able to stifle the use of chickens in a shared BSCS biology room because no other facilities existed. The atmosphere created by the raising of chickens did create interest in biology but evidently not in chemistry.

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[1] ibid., pp.45-46. This is not high enough for sterilization by autoclave which requires two atmospheres.

[2] Ultrasonic disintegrators have the AAAS instrument identification number 136000.

Most small vertebrates can be housed in cages which contain bedding to soak up urine and water spills. These cages are washed easily in large, two-by-three-foot sinks. Frogs can also be cared for without normal water spills. Chicken brooder water troughs do spill water normally, but the amount is slight. Access of supplies, such as feed bags and bales of bedding, to all animal rooms is aided by a ground floor room location.[1] If large animals or many animals are raised, floor drains are necessary; and this also creates problems for rooms above ground level.[2] Ventilation should be separate from room systems and vented directly. Intake air should be heated, possibly from the hall.

Invertebrate aquatic animals will have aeration problems. Pressurized, filtered air could easily come from exposed wall mounts behind counters supporting the aquaria and culture dishes. Drain troughs and frequent taps would aid in cleaning aquaria; distilled water might be needed for cleaning in polluted or highly treated water districts. Marine aquaria are available which recirculate synthetic "salt-water." Some high schools near the ocean circulate ocean water in large, permanent, glass-lined water tables.[1] Such natural culture conditions have many problems, and it may be well to investigate the synthetic systems.

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[1] McKinsey 1966 p.181.

[2] Evidence of poor leakproof design is found in McKinsey 1966 p.181.

With large organisms, including vertebrates, balanced or mixed aquaria (non aerated, but has plants) can be illuminated with artificial light. Cooling and amperage concerns are present when high numbers of fluorescent lamps are contained in a small space.

The growing of plants under artificial illumination is rapidly becoming the preferred method.[2] Experiments are facilitated by variable length of illumination (even the smallest light leak will spoil this experiment), and by the ability to vary growth factors of light quality, humidity, and temperature. In vocational agriculture such illumination is often coupled with greenhouses.[3] A major project will be to determine requirements of built-in growth chambers, but a number have been successfully used. Humidity control, temperature control, and high amperage circuits for fluorescent lamps covering the ceiling are services required along with water and drains. Lights require upward draft cooling to maintain optimum spectra. Commercial units can be purchased with excellent controls, but the work space is small and the cost is high. Small units for two to four teams of students can be constructed without regard to temperature and humidity regulation services. (Polyethylene sheeting can be used to maintain humidity.) The light bank on even a small unit will require a thirty-amperage circuit. Such a unit is needed for the BSCS Plant Growth and Development Lab Block.

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[1] See Woolever (1963) for a description of such marine facilities.

[2] Grobman (1964 pp.21, 35) urges homemade growth chambers as equipment items. The Department of Agriculture at Beltsville, Maryland, has pioneered in development of large growth chambers.

[3] Drawbaugh (1963 p.16) has said this.

Apart from experimentation with plants, supply of plants will facilitate undirected inquiry. This means that a large facility is needed to maintain plant stock. Often mature plants are needed for experimentation, resulting in a thirty- to sixty-day wait after planting. Greenhouses have traditionally been constructed for supply purposes in many high schools,[1] but the use of these facilities after construction needs to be investigated.[2] It may well be found that the lack of automatic facilities has forced teachers to abandon the troublesome use of greenhouses. Greenhouses which present little difficulty in use will include automatic ventilation, humidity, and heat control. A direct heating line to the boiler is recommended for maintaining heat while the rest of the school is cold.[3] Small greenhouse units present difficulties in controlling temperature.[4] It appears that with their controls artificial growth chambers could replace greenhouses and offer more to education. If greenhouses are constructed, it has been suggested that accessibility for heavy and bulky items be insured.[5]

Microorganisms have long been overlooked as laboratory organisms for high school biology; they include protozoans, small algae, bacteria, fungi, and bacteriophage. Algae will need light, preferably artificial so that illumination can be controlled.[1] Cultures can be shaken or stirred by small electrical appliances. Other microorganisms can be aerated by pressurized air or by shaking in heated water baths.[2] Stock cultures of bacteria, fungi, and phage are maintained under refrigeration in dormant state. The appliances mentioned indicare a high amperage demand.

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[1] The acceptance and recommendations for greenhouses are documented by Cox 1966 p.41, Hufziger 1954 p.12, D.E. Miller 1962, Munch 1958 p.419, and NEA Research Division 1959 p.29 (the latter reporting that ten per cent of schools had them, thirty-one per cent of large schools).

[2] Thirty greenhouses associated with vocational agriculture departments in Pennsylvania are in major disuse due to a lack of automated facilities (Drawbaugh 1963 p.5).

[3] Recommended by Hollenberg 1960 p.31 and Drawbaugh 1963 pp.11-16.

[4] Drawbaugh (1963 p.11) states this.

[5] Drawbaugh (1963 p.11) suggested this. School Management (1963b pp.68-69) gives an example of inaccessibility.

Autoclaves of various types will facilitate rapid sterilization of media and glassware. Hot-air sterilizers (115 volt, 1200 watts) can be used for glassware and drying of pipettes (useful in non-microbiological experiments also). Autoclaves require at least two atmospheres pressure (fifteen pounds gauge pressure) in the steam line to which they attach. Self-generating autoclaves can be used in the absence of a steam line, but operation is slower. Generators take a half-inch gas line or 115- or 220-volt current up to 5000 watts. Slow generation will prohibit use during free forty-five-minute periods; therefore, steam lines should be provided. BSCS[3] recommends that a 220-volt kitchen range and twenty-six-quart pressure cooker be used for sterilizing. Cooling is a long, time-consuming process if water cannot be run over this large pressure cooker. Microbiology also needs gas outlets for Bunsen burner operation and large quantities of distilled or deionized water.

Chemistry.—Chemistry laboratories generally involve the same services as biology with more concern for ventilation and less for high-amperage electricity (apart from hood motor circuits). Hoods should vent at 50 to 125 cubic feet per minute per square foot.[4] Air scoops may be substituted for hoods for versatility and space savings.[1] Ventilation is an excellent precaution against corrosion in laboratory and stock rooms.[2] Small ventilation ducts should have few bends for adequate evacuation of fumes. No expansions of the duct size should be allowed, since accumulation of explosive gases might occur. Room air should be vented directly to the outside, and corridors should not be utilized as "balancing" spaces.[3]

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[1] See affirmation by Grobman 1964 p.21.

[2] Hot-air shakers are used for large volumes.

[3] Sussman 1964 pp.73, 64.

[4] Lewis 1962 p.41.

Individual sinks or troughs are necessary along with large washing sinks in the laboratory. Safety showers also require drains and plumbing services. If floor drains are connected to sewers, a danger of explosion exists due to gas leakage up through the drain which has no trap. Safety showers may well be connected to dry wells. Fuel gas, hot-cold water, 115-volt electricity, and possibly piped distilled water are needed services. Vacuum and steam (1.5 atmospheres) may aid the conventional class and are often necessary for second course chemistry. Vacuum of high quality can be produced with cold water faucet adapters.

Physics.—Physics services can be more flexible than those for chemistry, since plumbing is not utilized at every site. One sink and hot-cold water is sufficient for a class of twenty-four. Compressed air and vacuum lines could be used, but they tend to detract from flexibility inherent in using movable tables—portable pumps are recommended. Portable gas burners can supply necessary heat.[4] Electricity needed throughout the room may be provided by floor and ceiling outlets.[5]

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[1] Lewis 1962 p.92.

[2] Werner Schramm (1960) will be helpful.

[3] For ventilation services, see Lewis 1962 p.90.

[4] A need for fuel gas can be seen in PSSC 1965a p.11.

[5] Movable tables with 115-volt electricity as the main service are required according to Harvard Project Physics 1965; PSSC 1965a pp.12, 32, 33; and R.C. Whitney 1963b p.84. NCSC cites that some equipment requires 220 volt (NCSC 1964 p.56).

Several small circuits of 115 volts may avoid "voltage drop" when many instruments are being used in a class. Portable units can supply DC power. Power panels are not needed for most physics courses.[1] All sciences require blackout curtains for visual aids, but physics requires lack of light for wet experimentation in optics.[2] Shop facilities for physics require sixty-amperage circuits.

Integrated courses.— Services for integrated courses may be formed from separate facilities or by making all rooms self-sufficient for multiple instruction. Chemistry and biology services could be arranged around the perimeter of the multipurpose room, with earth science and physics using the central portion for flexibility. A complex of rooms possessing specialized facilities would work well if topics in classes were staggered. On the other hand, if the sequence of topics means much in integrated courses, probable overload of specialized facilities would indicate that multiple science rooms are needed.

Situational space

"Product" and "social impact" goals have methods which suggest close association with the library and humanistic disciplines. If answers are to be found in the library and textbook, little distinguishes this type of science from other book-oriented courses. The library is frequently used during class periods as preparation for later studies.[3] "Social impact" could well be integrated with plays, music, and art displays. "Social impact" and "world view" also suggest close coordination with social studies, but situational space need not be evidence of this relationship.[4]

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[1] Examples of such panels are in Palmer 1961a p.281, 1961b p.8; and School Management 1963b p.67.

[2] Visual aids in PSSC are mentioned in Finlay 1962 pp.67-69. Experimentation is noted in R.C. Whitney 1963b p.53.

[3] This is supported by Brown 1965 p.91.

[4] Close coordination is urged by NSTA 1960b pp.165-182.

"Process" courses also demand use of library materials, often for only part of a period. Radial access to the library from individual rooms will minimize distracting hall noise. But the use of the library is only one aspect of scientific research activity to be taught in "process" instruction.[1] A door leading to outside areas aids in reducing corridor noise during field trips and gives direct access after hours. Most rooms should have direct access to preparation rooms and appropriate ancillary facilities,[2] and separate exits should be designed for non-instructional areas.

Association with shop facilities could foster the establishment of engineering instruction in what is now crafts training. Equipment used by engineering and physics courses could be shared, a situation leading to team teaching in these two areas. Scott Engineering-Science Corporation of Pompano Beach, Florida, manufactures small engineering equipment models that would make the tie between physics and engineering quite apparent. The service trades would appreciate the background of graduates from such a curriculum. The practice of having separate physics shops seems poor affective training for college- and non-college-bound students. Manufacture of scientific equipment could serve as vocational training and function in setting up a model relationship between technical and purely scientific aspects of our society. Proximity would lead to close relations between physics (and all sciences) and the vocational arts of metal shop, woodworking, machine shop mechanic training, drafting, electrical repair, and possibly glass blowing. Agricultural training would benefit from a broader foundation in pure science and could offer examples of application which aid in grasping scientific concepts. Such integration of college preparatory and agricultural education runs counter to Hollenberg's suggestion of completely separate facilities.[1] Agricultural experience offers examples of the "power" of science. Less and less can our population benefit from farm life which has seemed to instill intuitive understanding of physical laws when associated with good schools. The preparation of agricultural manpower has also shifted toward college which means that the college-bound agricultural student rarely finds adequate preparation in the very activities which would aid his understanding of science. Outdoor laboratories and farms should be within a three-minute walk from the classroom; otherwise, double periods are needed to accomplish most activities. Some outdoor facilities are so far away that observation of a phenomenon is ruled out, except by special field trip.[2]

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[1] This activity is advocated in Brown 1965 pp.123-134, Marean 1959, Schlessinger 1962 p.70, and Woodburn 1965 p.369.

[2] In some designs, it appears that business education has closer ties to physics than does shop (Perkins 1961).

With the coming of artificially illuminated growth chambers, the classical requirement for a southerly location of biology rooms is outmoded.[3] Other factors should take precedence.

The floor location of the science laboratory is debatable. The roof offers advantages for urban schools desiring to protect the greenhouse, but elevator service for heavy supplies must be provided. In areas having heavy snows, peaked roof construction can make storage space available or provide for compressors and distillation apparatus. Laboratories above the first floor must provide adequate waterproofing in the floor and noise suppressors for active feet and machines. The handling of hazardous chemicals and bulky equipment presents added danger in supplying upper floor labs. Ventilation of heavy, obnoxious fumes must be done well under the capacity of the ventilation equipment if upper floors are used; there is a tendency for fumes to flow down stair wells.[1] Despite such handicaps for top floor locations, New Jersey recommended such a location for physics and chemistry.[2]

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[1] Hollenberg 1960 p.3.

[2] The Lincoln-Way Community High School, New Lenox, Illinois, has experimental areas on the opposite side of a football field from the classroom area (in Sumption 1957 p.177). It would be interesting to see how often schools like this one use such facilities for non-agricultural students.

[3] Southerly exposures are recommended by various states in Martin 1960b pp.8, 9, 31. See also Sumption 1957 p.156.

Facility Research

Most facility research, though not all, has been of status study form. See Appendix H for a discussion of selected studies.

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[1] Savage (1964 p.16) cites this phenomenon.

[2] See Martin 1960b p.96. Pelham, New York, also placed a chemistry laboratory above biology, general science, and a lecture room (in Leggett 1961).

CHAPTER V

EMERGENT ISSUES RESULTING FROM THE USE OF THE MODEL

Some issues result from the peculiar picture given to educational specifications in Chapter One. These issues raised by the model are mentioned in this chapter.

Facility-method relations

Most of this paper has demonstrated that facilities can be reasoned a priori from methods. A specific example is the recommendation for classroom-laboratories when methods involve the inquiry laboratory.[1] This type of reasoning is used when the model suggested in Chapter One is followed. The reverse of this reasoning also suggests that facilities could tend to influence methods. That is to say, facilities could silently influence the outcomes of instruction. Educators may not be aware of the degree to which facilities influence the teacher's decision of which methods to use, and it is this decision which eventually determines which goals are accomplished.

An explanation of how facilities could influence methods can be based on sociological analysis of the cost and gain for personal action. If an activity demands high cost in time spent improvising or organizing space, then the gain must offset the cost enough for the successful competition with other activities. The activity with the highest gain (or if all have a net cost, then the least cost) will be adopted. For example, let us say that the curriculum guide calls for an exercise in electroplating for chemistry. (This subject may just serve as a medium for a "process" topic, or it may be the essential topic to be discussed in a "product" chemistry course.) The teacher has several alternatives in presenting the topic. He may lecture and discuss the topic symbolically, may give a Tested Overhead Projection demonstration with an electrolysis cell, or may ask the students to perform an exercise in the laboratory. The cost and gain of each choice are different.

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[1] Others have practiced this a priori reasoning: (classroom-laboratory) CHEMS 1963 p.6, Grobman 1964 pp.9-10, Martin 1962 p.21, Olsen 1962 p.29, PSSC 1965b p.1 Part II lab notes; (Trump recommendations) EFL 1960c and Trump 1959.

The lecture may not improve the students "product"-wise, but most teachers can rationalize this as "the students are not trying." Therefore the cost to the teacher is minimal, even if the students do not achieve the goals of the course. The teacher needs to spend little time in preparing for such a class. The gain may be large if the teacher can spend his time doing profitable things (establishing good teacher relations in the lounge or good student relations in a science club meeting) other than preparing for laboratory.

The TOPS demonstration would be little effort if the classroom had the proper services. But suppose the room cannot be darkened and all projections have to be done in the hall or auditorium. What now is the cost for our teacher? He must go through red tape to procure the auditorium and spend time modifying the projection facilities. To do this not only costs time but makes the teacher feel like an odd character, since no other teacher would think of such a thing. So he thinks of using the hall. He must find a way to power his projector—that is simple enough if hall projection is the normal procedure. He now must make sure that others are not using the hall for projection at the same time and must control the noise of moving stools or chairs into the hall. If he does not control his students in this difficult situation, he will lose face with other teachers. He may feel that students take good notes only when at their desks. It becomes obvious that the cost is quite high when using TOPS in inadequate facilities. The gross gain may be larger than lecture, since students might perform better on tests; and the teacher may gain respect for using new methods; but the net gain may still be smaller (or [illegible].

To do a laboratory in poorly designed space may even cost more. If separate laboratories exist and the course is "process" oriented, the entire point of the exercise may be lost by the time students gain access to the laboratory. Poor teaching would be attributed to the teacher if he waited for the laboratory, so he may try a dry lab. Or if he does wait, he ceases to teach "process" and is now teaching electroplating as a skill or "product." If equipment is hard to locate in various rooms (teachers may have taken some supplies to their own storage area), hours might be consumed in organizing the lab at high cost. Central storage facilities could have eliminated this cost. The gain might be high for a teacher establishing a reputation for good teaching, but for older teachers with established reputations the gain is less. The older teacher might rather maintain friendships in the faculty—which takes time. Therefore the young teacher might spend the hours looking for equipment, whereas the older teacher finds the cost too high and the gain too low.

With facilities designed for lecturing, lectures would be the activity with the least net cost or the most net gain. With facilities designed for demonstrations, the demonstration would have the highest net gain. With facilities designed for laboratory work, the laboratory exercise would have the highest net gain. The activity with the most reward or least penalty for the teacher will be the activity done. In theory at least, this could explain how facilities determine methods.

Space as a limiting factor

Regardless of the cause, space limitations can be regarded as constraints upon activity. Can it be predicted that with certain spaces only certain activities will occur? Space-method research at this level is similar to ecological study. One can utilize knowledge of predictive relationships between plants and soil conditions without knowing the physiological cause of the ecological relationship. So too, one can utilize knowledge of predictive relationships between facilities and methods. The reasoning given in this paper can direct empirical investigation of spaces now being designed and used. Are facilities a limiting factor in individual projects? Do schools with greenhouses utilize more living material in their classes than schools depending upon window sills or direct purchase of specimens? Is a growth chamber much better than a greenhouse for allowing plant physiology experiments? Does a lake limit the extent of field work that could be done if other features, such as a swamp, were substituted for the lake?

Of course in any such research, the causes for poor utilization of greenhouses or lakes would be useful to know. Teacher training might modify the utilization of some facilities if technological training was needed. The fear of a possible drowning might cause poor utilization of lakes; such a cause would indicate a low value for lakes in site selection, since the cause of poor utilization is not amenable to change. Facilities may attract teachers who would conduct current activities under any condition, but such a finding is still useful and theoretically stimulating—in effect, the interpretation concerns the formation of niches for certain types of teachers.

Even without known causes, a correlation showing that separate laboratories hinder the proper teaching of "process" courses would have use. Educational specifications could be drafted with such correlations in mind. If greenhouses are not used by seventy-five per cent of the schools having them, it is foolish to spend the money constructing a greenhouse while hoping that the school will be one of the twenty-five per cent which does utilize this facility.

The factor of space may be limiting or instructionally restrictive only when in conjunction with other factors such as school law, teacher turnover rate, teacher training, ability of students,[1] architectural technology,[2] length of the school year,[3] operating budget of the school, and student grouping procedures. Many teachers feel that poor lab facilities are limiting,[4] but whether this is true or not should be investigated. Many educators would agree that facilities can be limiting factors,[5] but when is a certain facility design the key to increased efficiency? The theory of detecting limiting conditions centers around one test— if the factor is varied as an independent variable, the dependent variable should follow suit. If laboratories are placed in a school which lacks the budget to purchase equipment and supplies, the methods of teaching will not change. Space is not considered limiting in this case. If unlimited funds are provided, then funds are no longer limiting; now available student time or space could be limiting. The task of isolating limiting conditions is not impossible; ecologists have been doing it for decades. Final answers are never achieved, but each investigation stimulates more research which in turn allows more precise prediction concerning the consequences of spatial factors.

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[1] D.E. Miller (1962 p.266) feels that facilities are limiting for all but the exceptionally intellectual individual.

[2] Franz (1965) gives an example of a technological innovation which may influence the restrictive nature of sloping floors in lecture rooms. Fold-away tiered seats would allow flat floors to be utilized for large group instruction.

[3] Air conditioning may be a limiting factor for twelve-month-a-year schools.

[4] For evidence of this, see Bowles 1964 p.111.

[5] Martin (1960c p.31) is good support for this statement.

Suggestive space versus flexibility

One of the major implications of the model has been that economical facilities cannot be designed for all methods and all goals. The choosing of which goals to adopt in certain grades is a local matter. With the coming of better tests for "process" goals, research will be able to guide communities in choosing which methods they would find most effective. Facilities can then be designed to permit implementation of the best methods. But the facilities may be found to do more than just permit activity, they may silently "suggest" certain activities. Space may not just be a limiting factor, but it may also be a stimulus.

With empirical research, it may be found that a type of supervision can be exercised by the creation of "suggestive space." The presence of a growth chamber may suggest the raising of plants to the teacher. The teacher might act upon this suggestion as long as something else is not limiting.[1]

The theory of suggestive space is in essence a reverse functioning of the model in Chapter One, but it does not find its cause in the cost-gain theory presented earlier. The causes of spatial suggestiveness are buried in the mysteries of curiosity and creativity. The phenomenon needs to be verified in school environments. After the phenomenon is recognized, adequate research can be done on its cause.

The idea of suggestive space raises an issue with the concept of flexibility. It would appear that to suggest an activity, a space must be fairly specific. The loft concept of design suggests very little, other than flexibility itself.[2]

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[1] That is to say, if the teacher can purchase seeds and materials, the suggestion given by the presence of the growth chamber might be followed.

[2] The teaching of science in schools without walls is not stressed in a booklet written about such flexibility—EFL 1965. According to some students from flexible schools, such as in San Mateo, the method in science was always dry.

John Lyon Reid's school in San Mateo, California, is a prototype of loft-plan flexibility.[1] Walls are bolted to the ceiling, and no fixtures are on the walls. The services are provided at supporting posts which when connected directly will form squares, twenty-eight feet on a side. Plumbing is located in alternate rows of posts. At the most, two posts are in a science room[2]—meaning one sink per room with two centers of electrical and gas outlets. This type of flexibility hardly permits or suggests "process" methods. What science facilities should have is well structured facilities with no dearth of services. Gas and waste-disposal services require fixed walls if they are to be available in quantity. To have hoses of gas and water running from a central utility post is hazardous to say the least. But this example is only one type of flexibility. The concept of flexibility will now be examined in greater detail.

During the last decade, science education has seen a deep change in methods; this change has challenged the flexibility of our schools.[3] Flexibility became a byword of architectural excellence, having essentially three meanings: (1) quick convertibility fostered by easily changed partitions, utilities planned with foresight, and structureless walls; (2) versatility in the multipurpose use of a static facility; and (3) design for easy structural expansion.[4] How else was there to plan a school, the educational specifications of which might change several times during the building's minimum life expectancy of fifty years?[5] No wonder architects took refuge in the term "flexibility,"[1] when such thoughts as "Building for the 'Superintendent After Next'"[2] guided our educational specifications.

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[1] This school is described in EFL 1960d. [2] ibid., p.14.

[3] See Cramer (1963 p.6) and Martin (1962 p.20) for support of this statement.

[4] Paseur (1959) brings out these meanings in a well known architectural article.

[5] Life expectancy is borne out by Brubaker 1962 p.197, EFL 1960b pp.60-61, and Hurd 1954 p.2. The question is a rephrasing of several statements, an example of which can be found in EFL 1960d p.13.

Suggestive space does not conflict with flexibility for *expansion*. It may sometimes conflict with multiple use of a room—*versatility*. For example, a room cannot serve as a plant growth chamber and a darkroom at the same time, but such a room could be changed over to either purpose. Multiple use of laboratories can be facilitated with Hamilton Roto-Labs mentioned earlier or with folding tiered seats. Multiple use is probably not well done with "process"-oriented chemistry and physics. Physics requires serviceless tables, while chemistry needs plumbing. The room could have both facilities if it were large enough; but it could be wasteful, since only part of the room would be used at one time.

The concept of *convertibility* must suffer if the space is to facilitate wet laboratory. For wet laboratory methods to be suggested by a space, there needs to be something more than barren walls. Flexible situations may tend to suggest "product" non-wet lab methods. A case in point is the teaching of general science in the wings of a slanted floor, divisible auditorium.[3] For science, this situation is not flexible—it would have been the appropriate design if the school had adopted "product" goals and planned not to use wet laboratory in the junior high grades.

Flexibility is dependent on finances to a large degree. Air conditioning a nine-month school may be too expensive, although an air-conditioned school is more flexible in allowing an eventual twelve-month usage. Some flexibility, such as planning for future computerized programmed learning by providing coaxial cable conduits, does not cost much. Exposed plumbing in laboratories and ancillary facilities does not cost more and contributes to flexibility. Let flexibility exist where it can be afforded and where it does not conflict with support for intended activities.

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[1] Smith (1962 p.34) attacks designing poor schools under the term of flexibility.

[2] Both quotes are from a title in Murphy 1965 pp.3, 54-57. The title is of an article describing a school designed for a school system with little commitment for goals, hoping that the next superintendent could do something with the school. The school is praised for its flexibility.

[3] EFL (1966 p.7) describes this innovation.

School research design

In some future schools, the enrollment will be so large that comparison facilities could be constructed in an action-research endeavor. Within one school, a researcher could keep several factors constant; he could randomize teachers and students especially in a school-within-a-school situation. Various facilities could be tested for achievement of the same goal. Thought should be given to financial and technical aid to carry out research activities under these ideal conditions.

Of course, the schools able to do this will be mostly urban so that generalization will be somewhat limited. Nevertheless, the opportunity to construct facilities in a manner enabling experimental testing of limiting conditions, suggestiveness of certain facilities, and efficacy of methods is an opportunity often overlooked.

CHAPTER VI

SUMMARY

This paper has presented a model for preparing educational specifications of internal space relating to science instruction in grades nine through twelve. Specifications were based on four basic determinants of space: (1) activities and sub-grouping, (2) size of total group, (3) services, and (4) situational relations. The model suggests that methods can be reasoned from goals with the aid of educational research. The model then indicates that facilities should follow from the methods selected for fulfilling the school's goals.

The paper stresses local autonomy in giving alternatives for each step in the model, but the paper does not allow for teacher autonomy in the selection of course goals. The teacher has little autonomy in selecting the predominant method, unless he allows some facilities to go unused. Teacher preparation is expected to improve, so that instruction can be versatilely performed by most teachers under any goal. The model allows not only architects but also teachers to know what is expected of them. This has advantages over giving the architect a list of specific features to be included in a building. The paper implies that it is impossible to teach economically and efficiently for all goals in one year. The model's use makes it difficult to be too comprehensive in the election of goals, a plight often associated with group endeavors and curricular guides. Other advantages of the model are that it makes educators examine their purposes, insures that methods are at least thought to support selected goals, and guards against the physical plant's influencing the instruction in a way antagonistic to selected goals.

The dominant goal issue was the "process"-"product" contrast. It was seen that "product" goals were associated with verifying laboratories and that "process" laboratories were usually of the inquiry type. Inquiry laboratories were best designed as classroom-laboratories with large ancillary facilities. If undirected, inquiry demands the largest storage facilities of all goals. Vivariums in "process" curricula were also discussed, with the recommendation that plants and microorganisms be given the most serious consideration in constructing facilities to supply living organisms. The possibility of dry labs was also considered, with emphasis on computer-centered programming.

Other important issues in methods included articulation of ninth grade with science background and twelfth grade options, diversity in the curriculum, and vocational agricultural and engineering courses having close connections with the science department. The importance of the ninth grade as a transition or preparatory grade in science was established; tenth grade biology was shown to be the predominantly terminal science course.

Specific recommendations were made for outdoor instructional facilities, ancillary spaces, the classroom-laboratory, the separate laboratory, and project rooms. A suggestion for empirical research to verify these recommendations was made. It was also suggested that some future large schools might design comparative facilities, thereby allowing rigorous experimental design in facilities and methods research. Use of such research would be in the fields of teacher training and school design.

The model's use generates two emergent issues which might be tested—

1. Are facilities a limiting factor in permitting activity to occur? Under what conditions does space become the limiting condition?
2. Do facilities "suggest" activities?

This paper differs significantly from orthodox architectural writings in not advocating flexibility for all possible methods. The paper asks for a commitment to a few goals for each course year, selection of methods as judiciously as research will allow, and design of "suggestive" space to carry out the educational program.

APPENDIX A

DEFINITIONS OF LABORATORY TYPES

Wet lab.—This is a laboratory which is manipulated by the student using—where appropriate—actual apparatus, organisms, and chemicals.

Dry lab.—This is a laboratory where vicarious methods are used to simulate a wet lab. Actual contact with the real subjects is avoided, but raw data are obtained. Models can be used by the student or a filmed or televised experiment can supply the data. Programmed teaching and teachers can also reply to verbalized "manipulations" given by students.

Verifying lab.—In this laboratory the answer or data are known before the "experiment" is done. The student is supposed to arrive at a foregone conclusion from his data.

Inquiry lab.—See NRC (1963) and CBA (1964 p.3) for comparison with the verifying laboratory. In the inquiry lab, the answer is not known by the student before the experiment is begun. Data cannot be fabricated with certainty, although the experiment is done with a prediction.

Directed lab.— In this laboratory the student is restricted in his activity by directions.

Undirected lab.—In this laboratory the student plans his own experiment but may be given an hypothesis to test. Often directed labs lead to undirected studies. An undirected verifying wet lab is effectively a demonstration using elective materials. Dry labs can be undirected as long as the giver of the data is capable of responding to the student's suggested action.

APPENDIX B

EXAMPLES OF LABORATORY TYPES

The following are sources giving printed examples of the laboratory types. The sources are not listed in the bibliography.

Wet verifying directed lab

Clifford N. Wall and Raphael B. Levine, Physics Laboratory Manual (New York: Prentice-Hall, Inc., 1951), pp.80-83.

Here laws are stated and verified (within error tolerance) by actual manipulation of equipment and obtained data. The specific experiment is "Exp. 35: Measurement of Resistance by the Wheatstone Bridge Method."

Grafton D. Chase, Stephen Rituper, and John W. Sulcoski, Experiments in Nuclear Science (Minneapolis: Burgess Publishing Co., 1964), pp.48-50.

Many wet verifying directed labs are designed to illustrate a concept; illustrated here is the half-life of a radioisotope. Explicit directions are given, even possibly an unknown radioactive source. However, the concept that is being illustrated is known.

Wet verifying undirected lab

John H. Woodburn and Elsworth S. Obourn, Teaching the Pursuit of Science (New York: Macmillan Company, 1965), p.371.

"Begin with this sample of white marble and show me some carbon obtained from it."

Wet inquiry directed lab

Florence Moog, Animal Growth and Development (Boston: D.C. Heath and Co., 1963), pp.27-33.

The directions suggest looking at the testes of testosterone-injected chicks. Students are usually surprised to find the testes are small in chicks exhibiting exaggerated secondary sex characteristics. The explanation lies in a feedback system.

Wet inquiry undirected lab

Chemical Bond Approach Project, Investigating Chemical Systems (St. Louis: Webster Division, McGraw-Hill Book Co., 1963), p.46.

CBA gives a good example in "Experiment 19—Movement of a Gas Through an Orifice." After discussing effusion rates of gases in relation to gas density (in the text), the student is asked to design apparatus for an empirical study of a related concept, leak rate, with orifice size as a variable.

Dry verifying directed lab

Chemical Bond Approach Project, Chemical Systems (St. Louis: Webster Division, McGraw-Hill Book Co., 1964), pp.310-313.

Here a law is stated and data is given to show the law is correct. The same could be done with film or television showing the apparatus as it produces the data given in the book. On pages 327-330 a phenomenon is demonstrated by pictures, data, and commentary.

Dry verifying undirected lab

The success of this type of laboratory depends on the flexibility of the data giver. The three examples given below illustrate variations in flexibility.

Joseph J. Schwab, Biology Teachers' Handbook (New York: John Wiley and Sons, Inc., 1963), pp.213-217.

"Invitation 42" concerning the cause of hunger pangs is an interesting example. From the standpoint of Schwab, this is not verification, since he indicates the cause of hunger pangs is not yet known. However, the student undoubtedly feels that lack of sugar in the blood is the cause. This presents the situation where the teacher is psychologically ignorant of the answer supposedly known by the student, a situation causing the exercise to be verifying for the student. In Schwab's case, the point of the exercise is not in "product" knowledge relating to hunger. The purpose of the exercise is to show some basic understanding of "process" in science. Various experimental ideas are criticized under the guidance of the teacher.

Physical Science Study Committee, Physics: Laboratory Guide (Boston: D.C. Heath and Co. and Educational Services Inc., 1965), III-5, p.44.

A suggested experimental design concerning Centripetal Force is requested. Data are not provided for interpretation, however. Note how the next example could easily be made verifying.

John A. Swets and Wallace Feurzig, "Computer-Aided Instruction," Science CL, (October 1965), 572-576.

This reference gives examples of computerized programming to simulate "laboratory work" in medical diagnosis. In this case, the verification exists only in the existence of a right answer. However, the student proceeds in an unknown circumstance—really an inquiry operation. By giving the student the diagnosis and asking him to proceed in order to prove the diagnosis, the instructor would make it a verifying lab.

This type of laboratory is closely allied to inquiry through its undirected characteristic. Rarely do verifying and inquiry labs serve the same purpose; this is an exception.

Dry inquiry directed lab

American Institute of Biological Sciences, Student's Manual: Laboratory and Field Investigations: BSCS Green Version: High School Biology (Chicago: Rand McNally, 1963), pp.36-38.

Data collected in laborious field work are given to the student in "Exercise 2.3: Factors Limiting Populations." The students graph and analyze the data.

Physical Science Study Committee, Physics: Laboratory Guide (Boston: D. C. Heath and Co. and Educational Services Inc., 1965), III-4, pp.41-43.

Data are provided for student analysis.

Dry inquiry undirected lab

See dry verifying undirected lab for examples closely related.

Joseph J. Schwab, Biology Teachers' Handbook (New York: John Wiley and Sons, Inc., 1963), pp.130-135.

Schwab introduces the pituitary-gonad hormone mechanism as a feedback concept in Invitation 25. If done before teaching about the female reproductive system, this type of mechanism is foreign to the student. In the invitation students suggest experiments that isolate the relationships between three endocrine glands—A, B, and C. The teacher reacts with data and reinforcing the reasoning of student volunteers.

APPENDIX C

ALTERNATIVES FOR LABORATORY UNDER PRODUCT GOALS

Early research in this area used primitive statistics. Stuit, Engelhart (1932) and Riedel (1927) criticize the experimental design and statistics of their own era. Cunningham (1956 p.71), in his summary of research, cites specific criteria of which two concern us: greater retention of "product" and immediate gain of information. Croxton (1929 pp.79-80) cites the trend of research as favoring laboratory for retention, but lecture-demonstration for immediate gain. Weidemann (1930 p.465), dealing with junior high studies, confirms Croxton's remarks but considers the differences intuitively insignificant. Duel (1937 p.800) published a sample of his "product"-oriented test. He intuitively felt that there is little difference in retention but that lecture-demonstration was favored over laboratory in his results.

Immediate gain of information was measured by Cunningham (1924) with matched pairs on IQ and grades. There was no difference when high school botany was presented by laboratory or by demonstration, but the analysis was done visually, rather than with covariance techniques now available. Kiebler and Woody (1923) proceeded to wash out any motivational effect of the lab when they only counted those students who had perfect attendance and good attitudes.

Anibal (1926) and Knox (1927) described the demonstration control classes as discussion classes, not the lecture type now found in college. "The instructor was careful not to teach by direct exposition in the case of the Test Group." (Anibal 1926 p.357) In the latter two studies, high performance and high ability correlated with demonstration whereas students of low ability performed better with individual laboratory. Today the appropriate statistics would be analysis of variance or partial r and multiple correlation utilizing point biserialization with nominal categories. These various studies should be considered only as leads to further research, since the statistics are faulty; despite originality with interaction design, rotation of groups, and matching by rank order.

Horton (1928) suspected that written tests would not reveal differences in laboratory and demonstration. Kruglak (1958) confirmed Horton's thoughts with a laborious series of studies. However, both might be overlooking a phenomenon by quickly assuming that skill acquisition is the legitimate goal of laboratory. (Kruglak 1954, 1953; Horton 1929-1930b) The phenomenon, of which I speak, is the effect of the item form on what is measured. If ". . .the form of the items largely determined the score received" (Cronbach 1960 p.371), an existing difference between "product" mastery gained under different conditions might have been masked. The remedy of this complication is to change the item form and not the content validity of the test! (see Kruglak 1952) Since item form and content validity are often inseparable, this task will be a difficult one; it is not theoretically impossible.

Perhaps as a natural result of misgivings about the goals inherent in the early "product" testing of laboratory outcomes (see LeConte 1931 and Riedel 1927) or possibly because of a trend to "process" goals for science education, modern research has rarely addressed itself to "product" outcomes. Rainey (1962) found no difference in "product" mastery when laboratory was highly structured or undirected. His "within treatments variance" may have been high because of individual reaction to the treatments. Boeck (1956) found no difference in main effect of method in a three-way analysis of variance involving demonstration, reading, and combination vs. level of reading vs. teacher. Mean student IQ was a covariance adjuster of class achievement means. Using class means because of non-randomization of pupils resulted in a low N with only three teachers. The only significant variable was teacher main effect. (ibid. p.97) Adding a lab practical identification test of mirror images and not using covariance, the interaction between teachers and method became significant at the .01 level. This latter finding may attest to the need for flexibility, but quality of teachers would change the results from one study to another. Boeck's experimental treatment lasted only four days, which has advantages of minimizing contamination.

APPENDIX D

DRY LAB ALTERNATIVES FOR PRODUCT WET LAB

The use of research conclusions from comparison of methods is especially hazardous because of recent attempts to improve teacher training. Many studies have been conducted under conditions of severe teacher shortage which would indirectly hamper control method performance. Eventually, teachers may become proficient at many methods, thereby lessening the statistical teacher-method interaction. It is even less sound to say that television or film will be an adequate substitute for a teacher in the future. The teacher has little part in managing filmed courses, a situation which may be advantageous with poorly prepared teachers and may override disadvantages at the same time. The adjunct use of films, well managed by the teacher, has obvious value in teaching topics such as biomes or complicated experiments. However, this paper is primarily concerned with the decision to minimize services and create a space less flexible and less costly. Such a decision would place laboratory training solely in the television or film viewing classroom.

Rulon's classical work on films showed that films in general science could make significant gains with excellent retention in "product" attainment. (See Rulon 1933. Pages 76-77 and 100 give gains results with retention. Pages 105-106 show "product" was measured.) Fletcher G. Watson (1963 pp.1044-1052) reviews research which attempts to test the assumption that students can achieve mainly "product" goals by not actually manipulating materials. Films can be made so that data collection, calculations, and conclusions must be made by the student.

Such films could be directed-inquiry dry laboratories, but the studies using these films relied upon "product" measures such as the Cooperative Test Series.

Reed (1962) investigated replacement of chemistry laboratory work. He found no significant difference in gain or retention between those who saw the films and those who had the alternative laboratory. (ibid. pp.104, 105, 136) But, as usual, conclusions appear more clear than the investigative procedures warrant. One wonders about the effectiveness of teaching, since no significant gain occurred in the low-ability control group on the "product"-oriented criterion test. (ibid. p.119 for statement of no gain) Although three forms of the test were available, he used only the same form for pretest, post-test, and retention. This may have sensitized the students or made them test-wise. It is not clearly understood how he covaried for various aptitude and achievement factors when he used t-tests in comparing gains.

Reed's doubt that skills could be taught by film (ibid. pp.68, 73) was put to test by Brosius (1965) who investigated the value of dissection exercises in biology. Giving colored films of dissection, Brosius found more factual knowledge was imparted, including the ability to identify structures during a lab-practical test. No pretest of knowledge was given and no randomization occurred. No significant difference was found in skills gained (this variable was pretested); the criterion was the investigator's evaluation of dissection (was this biased?) plus a dexterity test in cutting plastic. The design suffered from the use of multiple t-tests where a three-way analysis of variance with pretest adjusters would have been more appropriate. (Such an analysis would have been method vs. type of animal dissection with classes as the third layer.)

While evaluating the John Baxter Chemistry Course on film, Anderson (1961a) committed errors not reported elsewhere. Seven film classes were compared with twenty-eight non-film classes, producing an N which was artificially inflated. Covariance included midterm SCAT scores obtained after the treatment began. Teachers were better prepared in the conventional classes and had, on the average, thirteen more years' experience than film teachers; evidently randomization of groups was not done. The combining of groups results in such inequalities as 16 experimental N and 280 control N. (ibid. p.256)

Popham and Sadnavitch (1960 and 1961) evaluated the Harvey White Physics Film Series and the John Baxter Films. Evaluation was "product" oriented, except for poor measures of interest and attitude toward the school subject. Concerned with the lack of Hawthorne Effect in the film group, these investigators might have overlooked that the main agent of that Effect—the teacher—was in a circumstance of minimized influence. (ibid. pp.2-3) Laboratories were given as supplements to the course; time was made by deleting films. There were highly significant results favoring the achievement of the control groups in physics (ibid. p.22), but no significant difference occurred in chemistry. (ibid. p.36) Attitudes reflected boredom. A questionable procedure appeared when covarying for intelligence they found significant differences in ability levels! (ibid. pp.24-25) It was not surprising that interaction of method-ability was found not to be significant when ability was held constant in scores used. (ibid. p.25) An alternative procedure could have used the Kolmogorov-Smirnov Test.

Champa (1957) found no significant findings while comparing three methods—supplementary television, supplementary films, and conventional teaching. Despite the lack of generalization, some aspects of design deserve comment. (a) Eight of Champa's twelve classes were conventional (controls), artificially inflating his N and creating unproportional n's for any analysis of variance. (b) The time of class meeting was controlled; the assumption that this should matter may deserve testing by adding a variable level in forthcoming experiments. (c) The use of matched groups rather than covariance technique and randomization may create a situation favoring the null hypothesis. The number of variables used in matching is considerably limited if matching is done within small tolerances. Randomization of students would have increased the N and therefore added sensitivity, even without covariance techniques. (d) The use of an entire year was made to avoid Hawthorne Effect, but it may still be present. (ibid. p.99) This interval gave findings which were easily interpreted by administrators; the ease in interpretation was the result of the experimental design glossing over contaminating variables. (e) The alternate forms of the Cooperative General Science Test were used in pre-testing and post-testing to avoid specific sensitization. Some classes received X form as a pretest, others received Z form. The alternate form was given as a post-test. Internal balance would have been better achieved if forms were distributed randomly within each class, or if the same forms were given to alternate rows. (f) Since the dates for testing were predetermined, this study tested the rate of a class's progress rather than its power.

Enders (1961) hypothesized that television would teach as much "product," or more, than conventional methods, consequently allowing a one-tailed test of significance. (This alternate hypothesis was reached by interpretation of other studies.) Enders ranked the "product" achievement (highest first): supplementary television, isolated television, and conventional teaching. Variables of socio-economic status of students, variation in Hawthorne Effect, and teacher-method interaction are suggested by the fact that intraschool results did not support inter-school findings. (ibid. p.77, cf. Engelhart 1958 p.348)

Charles Kelley (1964) in his review of television concludes that ninth and tenth grade science is especially well taught by television. In his review of television experiments totalling 37,000 pupils, he found 24% of the comparisons to be significantly in favor of television and never a situation in which control groups performed significantly better on "product"-oriented tests. (ibid. p.157) His actual thesis research did not reject the null hypothesis. Kelley had used past performance in past classes as an adjuster.

Engelhart's study of physics instruction by the Harvey White Film Series is discussed at length by Watson. (1963 pp.1046-1047) The Chicago studies allowed twenty minutes of a fifty-four minute period (five times per week) for teacher-student discussions. Students were required to participate actively in data collection and calculations. (Engelhart 1958 p.347+) Intellectual ability was indicated as another variable useful for further study. The use of Dressel's Folio No. 1 (Dressel 1954a) produced evaluation of "product" at a higher level than usual. In an hexographed supplement to this study, Engelhart stresses general dissatisfaction with the course on the part of students and 64% of the teachers.

APPENDIX E

EVALUATION OF INQUIRY LAB

The only national program actually concerned with enumeration of behavioral goals and their extensive testing has been BSCS (BSCS 1963, Wallace 1965). Despite articulation of many affective domain goals (E.W. Lee 1963), their tests have measured only the cognitive domain or mental skills (BSCS 1963). The BSCS instrument for measuring "process" attainment was largely independent of factual recall or "product." The test was called the Impact Test and is now slightly revised and for sale by the Psychological Corporation as the Processes of Science Test. This test has shown significant but extremely small differences between "product"- and "process"-oriented biology courses (ibid. pp.22-23, see also the test manual). The testing program had two large problems: (1) pretesting had been omitted, and (2) the evaluation was done prior to the release of commercial materials; therefore, the non-randomized sample was extremely biased. Specific analysis of the BSCS testing is dangerous because of incomplete research reports. The most dramatic departure from "product" laboratory, the lab blocks, performed the best of all on tests claiming to measure "process" goal attainment (BSCS 1963 pp.22-24, Sorensen 1966).

Several other studies have been tried but have little to recommend them as proof for the efficacy of "enquiry" or "process" methods (George 1965; Heath 1963, Olstad 1965, 1963; Hanson 1961). The evaluation of "enquiry" as a college-preparatory curriculum has never been done in a statistical manner, although it appears that the new curricula are allowing the upgrading of freshman courses. (See indications in Lisonbee 1964, Heimer 1963, Hurd 1964b, Marean 1966 p.18, Rainey 1964, Turner 1964.)

APPENDIX F

EVALUATION OF DRY LAB ALTERNATIVES FOR INQUIRY WET LAB

Supplemental use of films to aid students to gain affective awareness of "process" has been investigated. Wickline (1964) used the Facts About Science Test and found a significant difference favoring the films. The author is still waiting for a personal communication regarding how Wickline found interaction effects by multiple one-way analysis of variance. Wickline found that films decreased in value with higher grades (possibly a reflection of the poor test). Covariance adjustment should have been used, since his controls lost affective achievement (ibid. p.44).

Kazem's study (1960) used a test of dubious content validity (no answers were provided in the thesis) for measuring the effect of instructional (scientific method was the topic) and historical films on appreciation of science. He found that the methodological films were better than the historical, but a combination of both types was best. (Hurd [1964b p.291] questioned how this was done with equal time. Kazem gave half as many films of each type—one film each.) The statistics used were poor; by oversight, Kazem used a t-test for uncorrelated means to test gain (Guilford 1965 p.183). This has the effect of making him more conservative, but then he used a one-tailed test of significance which was not conservative.

APPENDIX G

A CASE FOR NINTH GRADE AS A PREPARATION COURSE RATHER THAN A TERMINAL COURSE

It is important to dispel the idea that ninth grade is the last science course for most non-college students. The most recent school year for which data can be obtained is 1962-63. Now discussed are the consequences of considering ninth or tenth grade as the final course for establishing "literacy" in science. (Most figures used are from NSF 1964 pp.123-125, and are verified by Obourn 1966 as very close estimates. Other sources are specifically noted.)

The total enrollment for grades nine through twelve was 11.7 million, of which 14% was in private schools. This leaves about 10 million students in public grades nine through twelve. Public school enrollment in courses given with modal grades was:

General Science	(9th)	1.827 million
Biology	(10th)	2.487 million
Chemistry	(11th)	0.859 million
Physics	(12th)	0.397 million

Since there had been approximately 0.5 million increase per year in high school enrollments (at a time concurrent with these figures), the distribution of the 10 million total enrollment should be adjusted to account for the increase:

9th grade	3.2 million
10th grade	2.8 million
11th grade	2.3 million
12th grade	1.7 million

Since 2.5 million students were in tenth grade biology (this figure does not include second course biology), it is apparent that 25/28ths or 90% enrollment exists for biology in its modal population.

Another possible comparison is between science students and their age group population. This comparison considers those who dropped school after ninth grade. These dropouts tend to raise the modal population ratio by decreasing the denominator—the modal population itself. Simon (1964 p.120) presents estimated figures which show 94% of ninth grade students who began school in 1956 will continue education in the tenth grade. This is the United States' current retention rate which reflects the best estimate for future school planning, unless we apply trend analysis. Simon (ibid. p.5) says that in the fall following our trial year, 2.945 million students entered tenth grade. At current trends, this was 94% of the ninth grade population in 1962-63 to whom general science would have been an option. This population would have been 240,000 stronger in ninth grade than in tenth ($0.94\,X = 2.945$ million). But even if 100% of these dropouts are added to the general science rolls, we still have fewer students taking general science than biology. It appears that biology is the true terminal course for most students, and therefore ninth grade can still be considered a preparatory science grade (most often giving general science as its course.)

APPENDIX H

FACILITIES RESEARCH

Certain research studies pertaining to school design can be divorced from methods, which would include activities and grouping. Research studies on site selection and effect of facilities will be discussed below. A few status studies will also be mentioned.

Site selection

There is a tendency to overlook school site implications for field work. Miles (1965 pp.17-18) recognizes the implications for field instruction in site selection but does not deal with evaluation of sites for instruction. This is a significant omission in a study which was to determine the important considerations in the selection of sites.

In Good's study, educational adaptability was ranked twelfth out of thirteen primary factors involved in site selection in Delaware (Good 1964 pp.112 and 116). One of the reasons for relegating instructional use of school sites to such an ineffectual amount of influence is that no procedures have been developed for quantitatively rating site instructional effectiveness. Questions concerning foundation cost are more easily answered than such a question as, "Will a swamp be more instructionally valuable than an artificial lake?"

Lauda (1963) has produced an analysis of instructional site utilization in a sample of schools in Pennsylvania. The method of sampling was not explained, but it was held to be representative of schools which had opportunity for site utilization. The tenth through twelfth grades of four urban, thirteen suburban, and eight rural schools were compared with the use of no statistics. Enrollments in the schools ranged from 490 to 2,556. Lauda felt that the absolute size of the school site was crucial in allowing outside teaching (ibid. p.113); therefore only those schools with over twenty-five acres were considered in the study (the maximum happened to be eighty acres). It might be more worthwhile to consider the usable features on a site or usable acres, rather than the absolute size. Many sites had features which would lend themselves to outdoor utilization: rocks (eight), boulders (one), ready access to lake (two), streams (eight), orchard (four), marsh or bog (five), timber (twelve), and gorge or other formations (four). Only a few schools had modified their environment for "outdoor" instruction—two suburban schools had garden plots, one suburban school had done reforestation, one suburban school had an outdoor classroom, three suburban and one rural school had a greenhouse, one suburban had a wildlife sanctuary (ibid. pp.36–40). Evidently, modification is coupled with school funds. Utilization (ibid. p.113) of natural or modified environment occurred most with schools having 500 to 999 students, but size seemed to make little difference. The type of community (urban-suburban-rural) made little difference in non-usage of natural features. Usage was highest in rural schools (45%), with suburban the lowest. Biology was found to be the main user (ibid. p.145), possibly due to grades picked—lower grades might see more earth science utilization. Natural history, not ecology, was the main use—indicating "product"-oriented schools. Short class time and lack of development of the wild areas were often reasons for non-usage. "Development" must be defined for later studies; it does not have to mean destruction of wild "exhibits;" but it can mean ease of access, planned routes for seeing the most in a few minutes. Lauda found that teachers with one to ten years' experience used the facilities more than older teachers (ibid. p.121). Teacher training could certainly be a contributing factor to non-use, but many other factors should be investigated.

Status studies

Several status studies deserve mentioning for further study. Many other studies have been done and are not mentioned here, since they achieved their purpose of showing trends or commonly held beliefs in school building. The studies mentioned here seed ideas for further investigation.

The first study is from the Office of Education (Obourn 1960). The sample of schools was random; every twentieth secondary school in the United States Office of Education files was used in the survey. (ibid. p.4) The file used was of 1951-52; and, as a result, findings now reflect a past era in school design. The great bulk of the 928 schools were inclusive of the last six grades (522), 246 were the last four grades, and 44 were grades ten through twelve (ibid. p.4). Two thirds of the sample had fewer than 500 pupils. This sample did not differ from the entire distribution of school sizes by more than 10% on large schools. However, geographical areas containing more small schools did report higher amounts than other more populated areas (ibid p.5). Regional subanalysis from the same random sample might give some officials more pertinent information. Three variables were investigated—type of instructional space (separate laboratory and classroom; combination classroom-lab for one science; classroom-lab for two sciences; multipurpose rooms having facilities for all sciences; and non-science classrooms with few, if any, facilities); subject being taught in such facilities; and the size of the pupil population in the school. Such a design lends itself to three-dimensional Chi Square or visual scanning; the latter was done. The criterion was the number of teachers teaching under a certain condition. The teachers might have taught more than one subject and therefore appear in more than one cell. The percentage of certain subject teachers teaching in certain facilities with certain school enrollments is independent of other subjects, however.

Certain provocative relationships appear. Some examples are:

1. (ibid. p.8) Large schools (over 500) use separate class and laboratory facilities in chemistry—much more so than in any other science. Small schools which cannot fill a separate laboratory most of the day are much better prepared to teach modern "process" curricula in their combination classroom-labs.
2. (ibid. pp.8-9) Non-science rooms are used much more for physics than for chemistry, especially in the 100-199 and over 500 population range. (The survey year was 1958; that was before PSSC had influenced the science curricula.)
3. (ibid. p.17) Similarities between biology and general science, instead of biology and chemistry, point to a change in curricula. It should be noted that in this paper, general science and physics have similar "process" facility requirements and biology and chemistry have similar requirements.

The study also tallied available ancillary facilities (ibid. p.10). The most prevalent facilities were for non-inquiry methods. Fewer than 20% of the teachers could encourage individual experimentation; only 8.1% had special project rooms (ibid. p.10). Detail in ancillary facilities and properties of instructional areas (ibid. p.10) is excellent and gives clues for future studies.

Felton (1959) in a survey of some metropolitan New York City area schools (within a 150-mile radius) found that individual investigations were not being given the guidance needed because students had to do experiments at home, a reflection showing the lack of facilities for such individual goal methods. (ibid. pp.28-31, 41). The study was biased since only NSTA members were contacted and fewer than 50% replied. Only a few were interviewed beyond the questionnaire. This bias would probably tend to select for the more concerned teacher. It was also found that large classes tended to require individual projects more often than small classes (ibid. p.18).

Redfield (1960) studied a representative sample of various types of white public and private secondary schools in Virginia. (The representation was based on the type of community revenue source.) Several interesting findings evolved. (1) Science clubs were found to be most successful when active experimentation was carried out as a club activity (ibid. p.56). Students were not allowed to do extra work in public school laboratories for 50% of the public schools. After-hour research was supervised by only 11% of public school teachers, whereas 50% of the private school teachers stayed longer than forty-five minutes after school for giving supervision for individual projects (ibid. pp.63, 65). (2) No laboratory facilities were present in 18% of rural public schools, and two out of the nine rural schools did not utilize laboratory facilities available (ibid. p.60). (3) The use of a room for more than one subject or the lack of double periods impaired the use of classroom-laboratories. (See ibid. p.61; this is Redfield's interpretation. In 1958 the NEA [1959 p.22] established that 57% of schools were not considering double lab periods. The NEA sample was biased in that the Far West and New England were poorly represented. The effect of double lab periods is to double the load for space.) (4) Storage space was a severe handicap in all schools (ibid. p.62). In 42% of public schools, unsafe storage of chemicals or equipment occurred because of easy access to unsupervised students (ibid. p.70). It should be noted that Wright (1961) confirmed the inadequacy of storage space in New York State's schools.

R.C. Whitney (1963b) compared physics space recommendation from experts as to group—science educators, teachers, and physicists—and then compared these to school construction (post 1950) in states having high expenditures/pupil day. Regional and group differences were significantly evident (.05) among recommendations. Specific discrepancies between method and facilities have been mentioned throughout this paper. The establishment of specific facilities was mentioned as dangerous in view of teacher turnover (ibid. pp.51, 54, 55), but the assumption of teacher autonomy underlies this recommendation of extreme flexibility. Supervision can be exercised to some degree by providing specific spaces, but possibly this is not as true in physics as it is in biology.

Effect of facilities

The effect of facilities has been investigated in several studies. The possible effect of facilities in implementing NSF curricula is a serious omission in McFarland's study of implementing CHEMS (McFarland 1965). Differences found in teachers (ibid. pp.114+, 125) could have been due to environmental factors.

Monacel (1963) found that some elementary teachers were successful in maintaining a status quo in the face of being transferred to new facilities. Grouping and methods were not affected by new facilities which would allow stress on individuals and flexible seating arrangements (ibid. pp.19, 25, 35, 109, 162-163).

Hanson (1961) attempted to find any correlation between performance on the Iowa Tests of Educational Development (ITED, Tests Two and Six) and facilities (among other variables) in Iowa schools. He used forty schools which differed more than one standard deviation from mean performance. Schools were matched according to ninth grade composite score on the total ITED. The study was continued over three years, tracing the growth of students on the ITED science relevant Tests Two and Six. Unfortunately for the comparison, facilities and equipment were in a state of flux; and the lower schools began to improve. The statistics were not fully explained, but variability may have been masked by other variables such as courses taken and teacher background. The facilities showed no significant differences. (ibid. p.120)

Drawbaugh (1963) investigated the effect of facilities on teaching greenhouse management. He also measured the acquisition of plant physiology knowledge and application of knowledge to farm crops. Three facilities were used with different students—classroom window sill, a school greenhouse, and a privately owned commercial greenhouse. (Artificial lighting was not utilized as a method.) Three methods were tried with each facility—an original "functional" lab method, lab manual with fill-ins, and the "normal" teacher's method. Three schools were assigned for each facility—method combination, giving a total of twenty-seven schools. From each school ten students were randomly assigned as participants. The statistics he used with the two dimensions of variables and three criteria were multiple t-tests. Multivariate analysis could have been done with the three criteria, or the criteria could be considered separately in a two-way analysis of variance. Comparisons on any two situations could have then been done by Scheffé's method or by Duncan's New Multiple Range Test. Drawbaugh had pretested and ranked his students in quintiles for covariance. He used correlated t-tests erroneously in his minor (methods) hypothesis; he thought different students being taught in one facility by different methods should be termed correlated due to common facility. Non-correlated t-tests did show significant increase in knowledge of plant physiology by students in schools owning greenhouses. Students working as "apprentices" in community-owned greenhouses showed significantly better gains than those using window sill work. (Alpha level was .05.) This "product"-oriented test supported his contention that vocational agriculture students did not gain from basic sciences presented in lecture or demonstration form. His measurements of application to farm crops showed no significant gains by any method or facility. In greenhouse management, school greenhouses were significantly better than window sills, but not better than community time-shared greenhouse instruction.

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ABBREVIATIONS

AAAS	American Association for the Advancement of Science
AIBS	American Institute of Biological Sciences
AIP	American Institute of Physics
BSCS	Biological Sciences Curriculum Study
CBA	Chemical Bond Approach or CBA Project, if used as an author
CCSSO	Council of Chief State School Officers
CEEB	College Entrance Examination Board
CHEMS	Chemical Education Material Study
EFL	Educational Facilities Laboratories
ESCP	Earth Sciences Curriculum Project
ESS	Elementary Science Study
IPS	Introductory Physical Science
NCSC	National Council on Schoolhouse Construction
NRC	National Research Council
NSF	National Science Foundation
NSTA	National Science Teachers Association
PSSC	Physical Sciences Study Commission